Search for new physics with τ leptons and b jets

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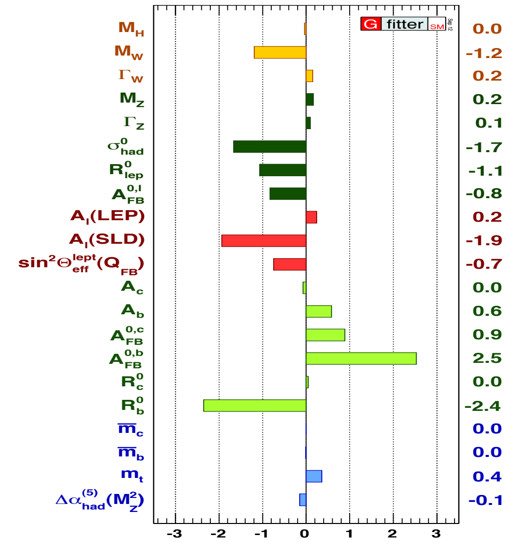
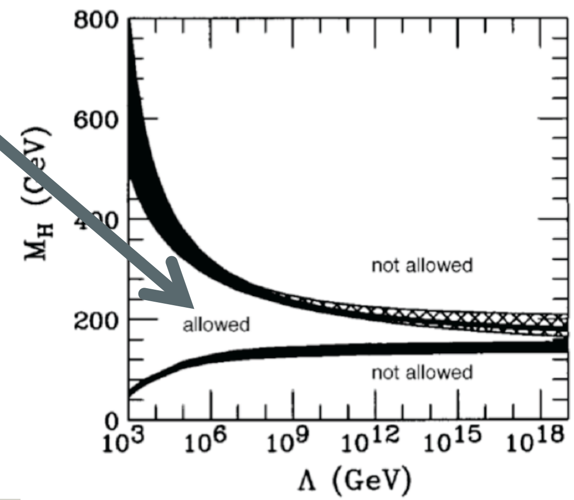
The Standard Model complete or not?

- As of today, the standard model is the best attempt to describe interactions of elementary particles
  - Successfully confirmed by the experimental data
  - A new boson is discovered with mass ~125 GeV whose properties so far are "the SM-like"

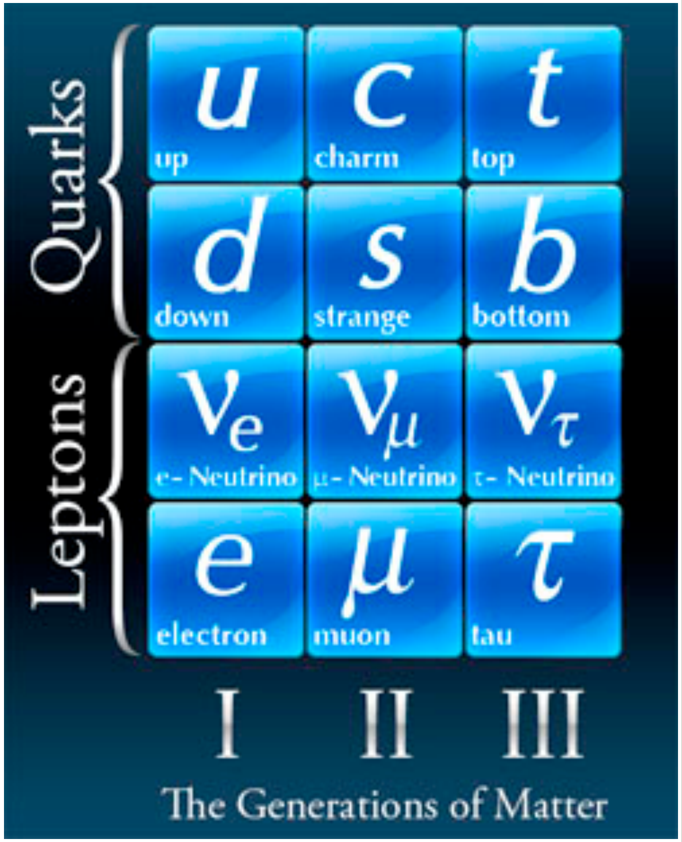


- The SM is not the ultimate theory
  - Naturalness problem – fine tuning is needed
  - Hierarchy problem – why $M_{EW}/M_{plank} \sim 10^{-17}$
  - What is Dark Matter?
  - Number of generations
  - Are there extra dimensions of space? etc..



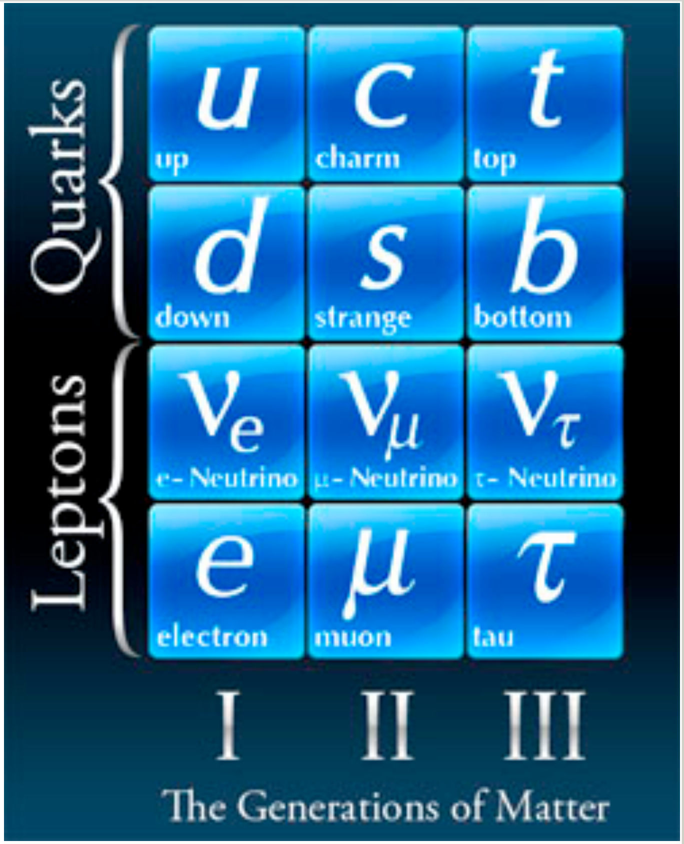
Why the third generation

- The Higgs couples to mass, thus fermion couplings are the most accessible via decays to τ leptons and b quarks
- Higgs boson(s) from minimal supersymmetric models (MSSM) have even more enhanced couplings to τ leptons and b quarks
- If SUSY is "natural", light 3rd generation squarks can be discovered at the LHC in final states with particles from the third family of the SM



Why the third generation

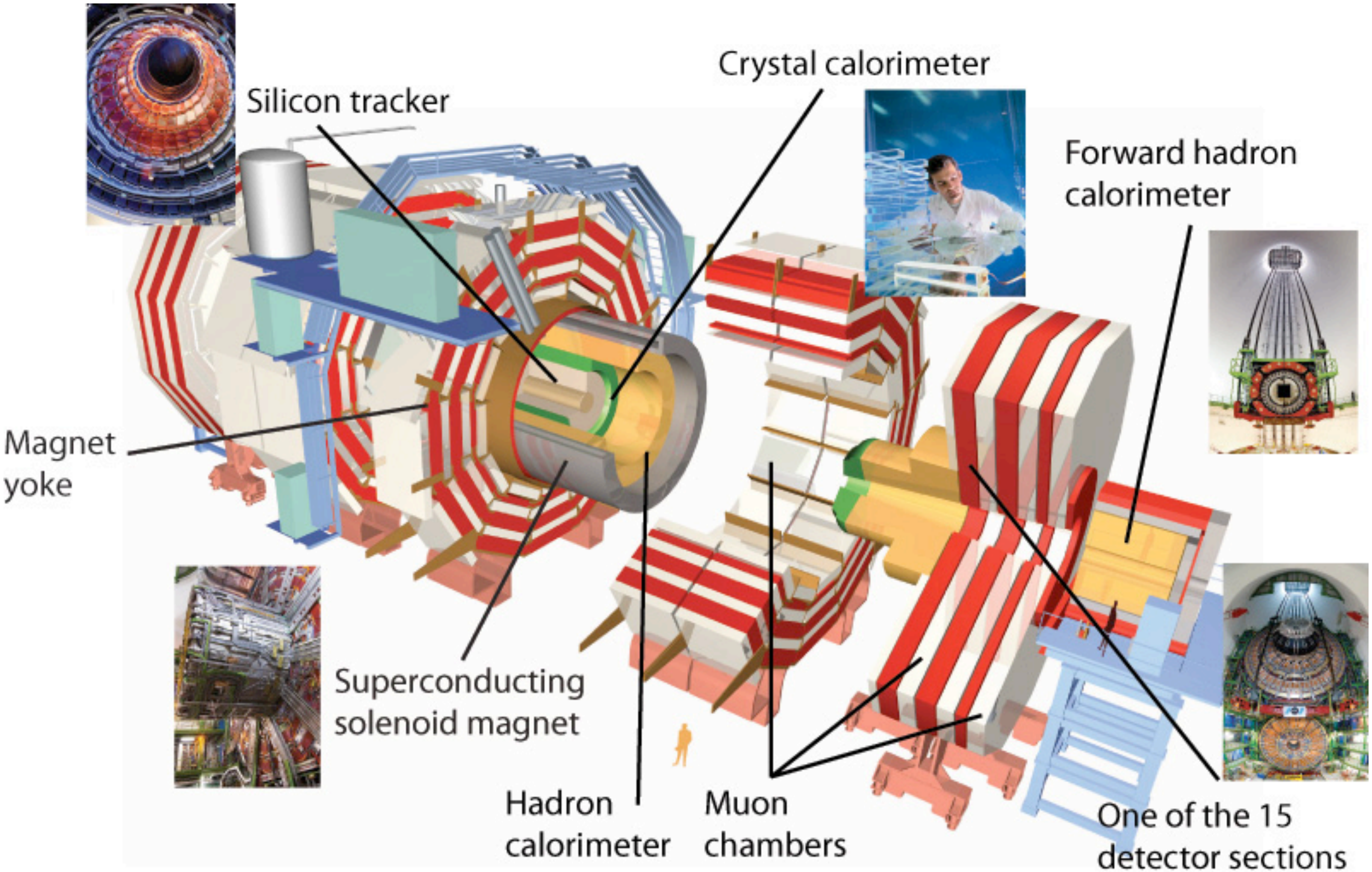
- Physics with third generation is also sensitive to other extensions of the SM
  - Models with suppressed couplings to light fermions: discovery can be made only with 3rd generation
  - Mixing between 3rd and 4th generations expected to be large: enhanced discovery potential
  - Symmetry between leptons and quarks suggest extra scalar (vector) bosons (leptoquarks): recent theoretical studies favor 3rd generation



In this presentation

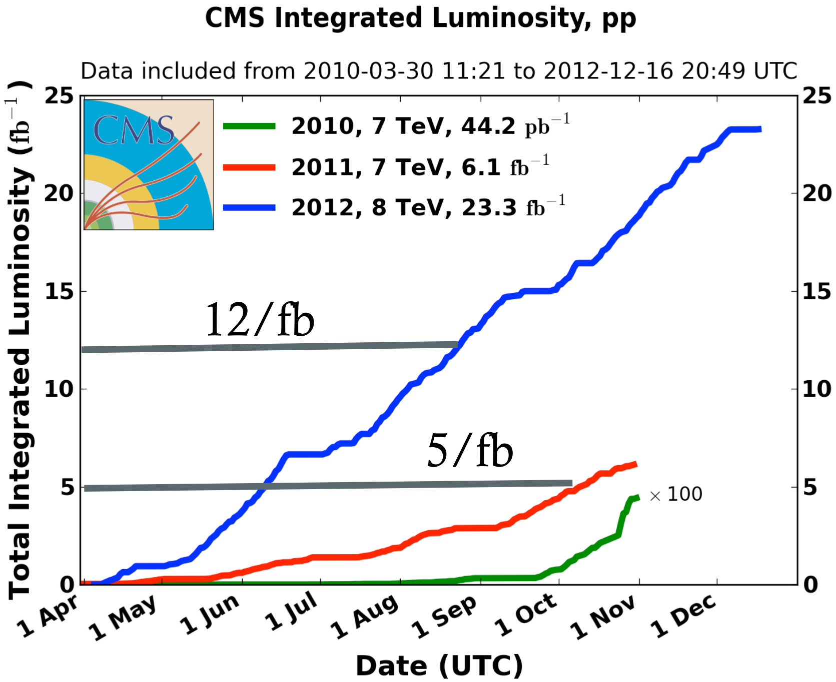
- Physics with third generation is challenging but exciting and could be sensitive to a number of SM extensions
- In this presentation:
  - Search for MSSM Higgs boson decaying to pair of τ leptons
  - Search for pair production of third-generation leptoquarks and top squarks decaying to pair of τ lepton and b quark

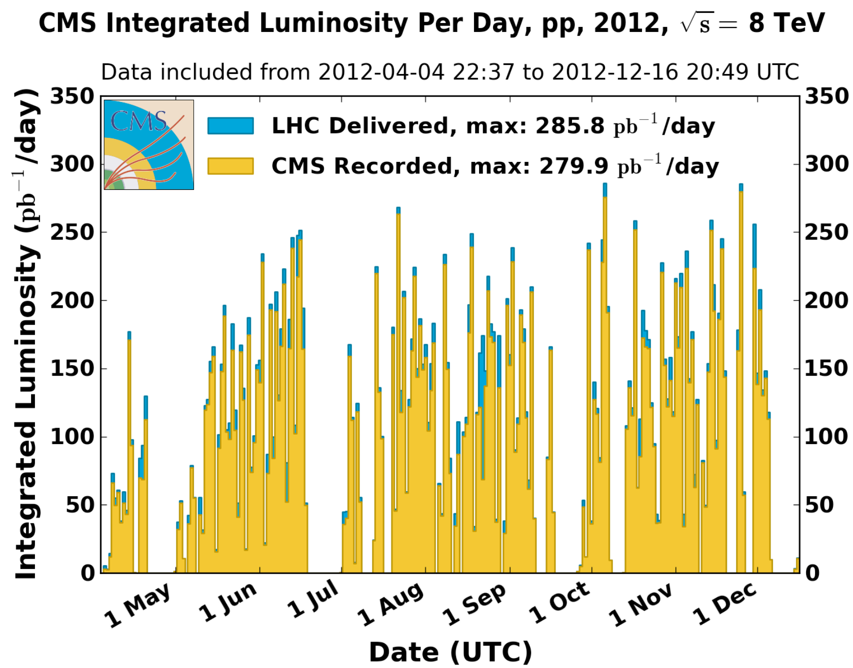
CMS Detector



Luminosity

- LHC performs incredibly well

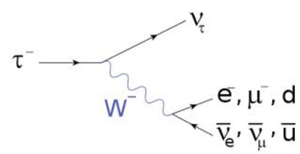




- CMS detector operates remarkably well
  - Data-taking efficiency ~95%
  - More than 97% of channels are operational

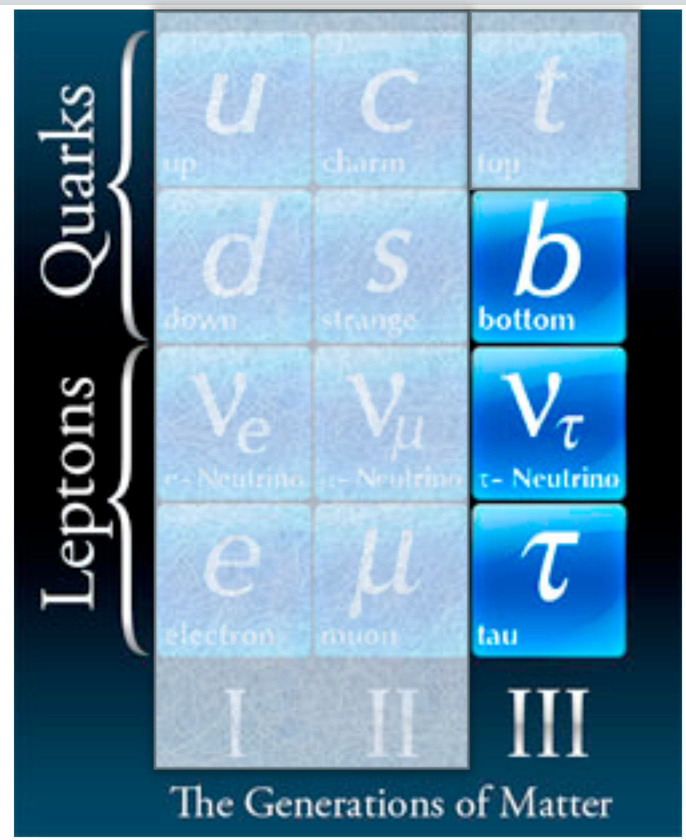
Final state objects

- Jets originated from hadronization of b quarks – b jets
- Missing transverse energy
- τ leptons



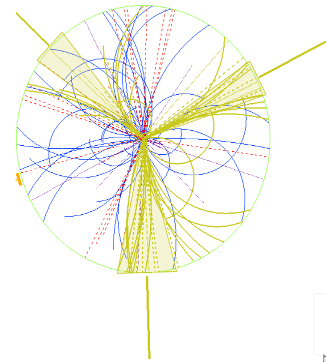
  - Light leptons or hadrons from τ

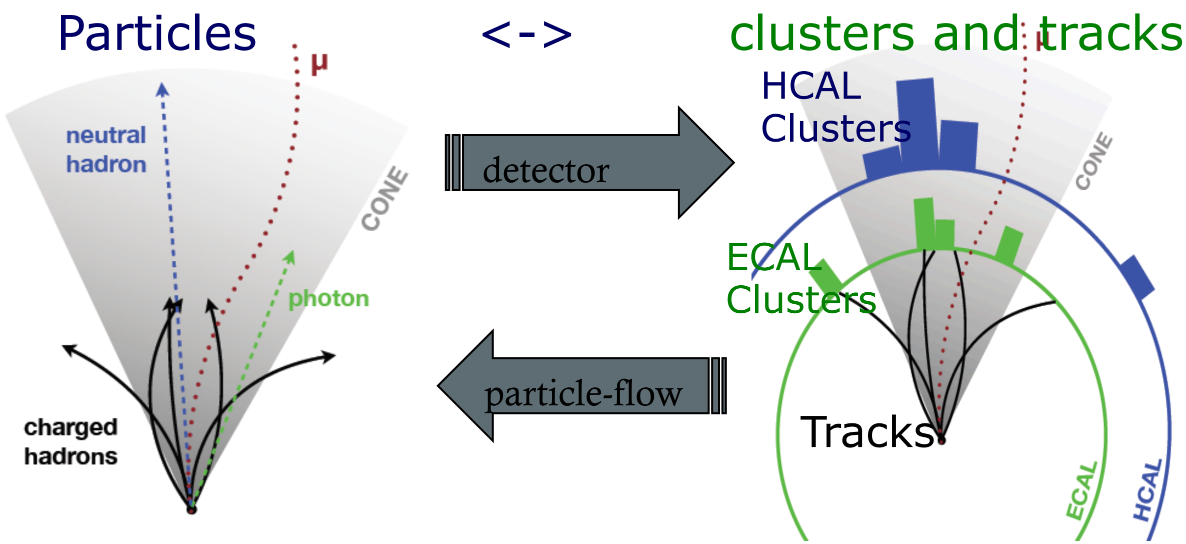
Decay Mode	Resonance	Mass(MeV/c^2)	Branching Fraction (%)
$\tau^- \to e^- \bar{\nu}_e \nu_\tau$			17.8
$\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau$			17.4
$\tau^- \to h^- \nu_\tau$			11.6
$\tau^- \to h^- \pi^0 \nu_\tau$	$\rho(770)$	775	25.9
$\tau^- \to h^- \pi^0 \pi^0 \nu_\tau$	$a_1(1260)$	1230	9.5
$\tau^- \to h^- h^- h^+ \nu_\tau$	$a_1(1260)$	1230	9.8
$\tau^- \to h^- h^- h^+ \pi^0 \nu_\tau$			4.8
Other hadronic decays			3.2



Particle Flow (PF)

- Algorithm to reconstruct all stable particles
  - Charged and neutral hadrons
  - Photons, electrons, muons





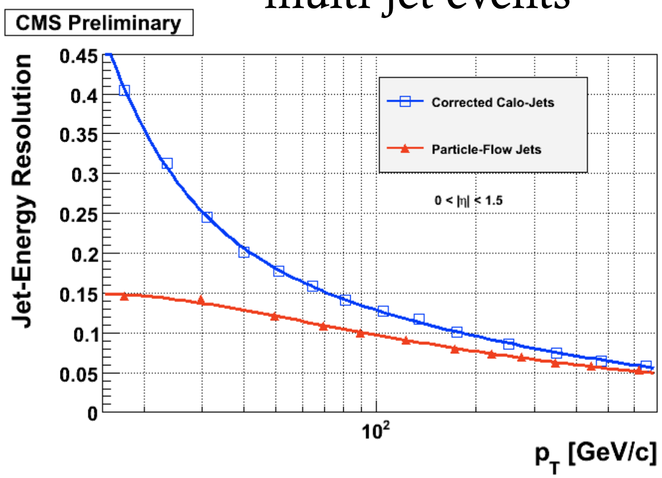
- Composite objects – Jets, τ leptons, missing transverse energy

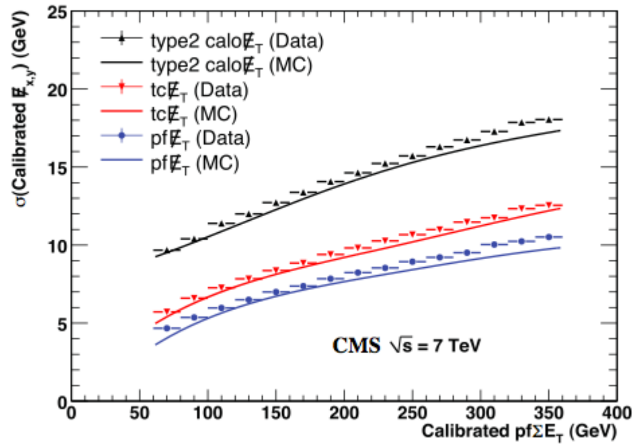
→ PF is crucial for reconstruction of different physics objects at CMS

Jets and MET

- Jet and missing E_T resolution are significantly improved with PF

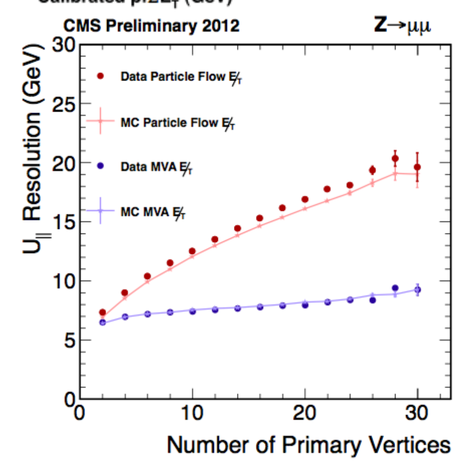
multi-jet events





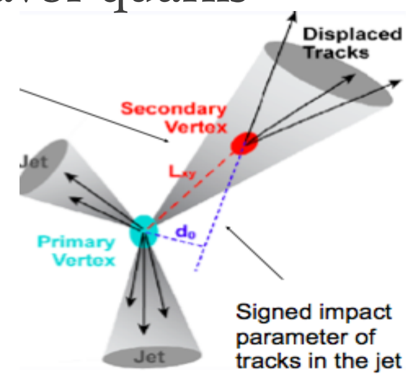
- More improvement of MET resolution
  - Using multivariate approach
  - Improvement of the resolution as a function of N_{PU}

→ Crucial for Higgs→ττ analysis

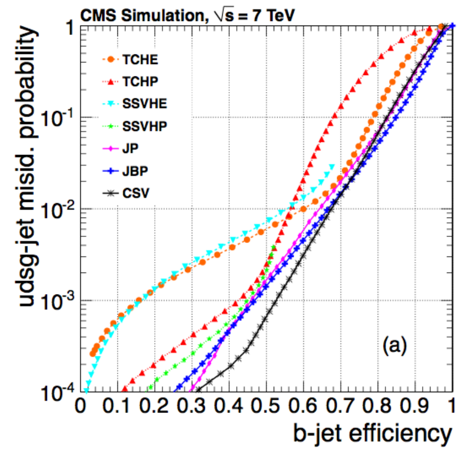


b jet identification

- Important to identify jets from hadronization of heavy flavor quarks
  - Large lifetime and corresponding decay length
  - High decay multiplicity and high p_T of decay products

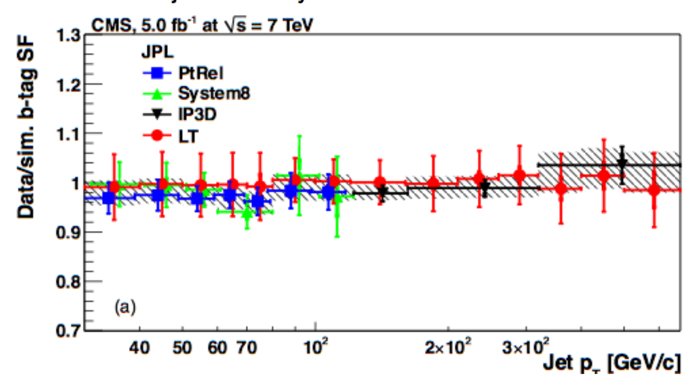


- Taggers are based on
  - track impact parameter significance
  - secondary vertex
  - Vertex mass
  - Flight distance significance, etc..



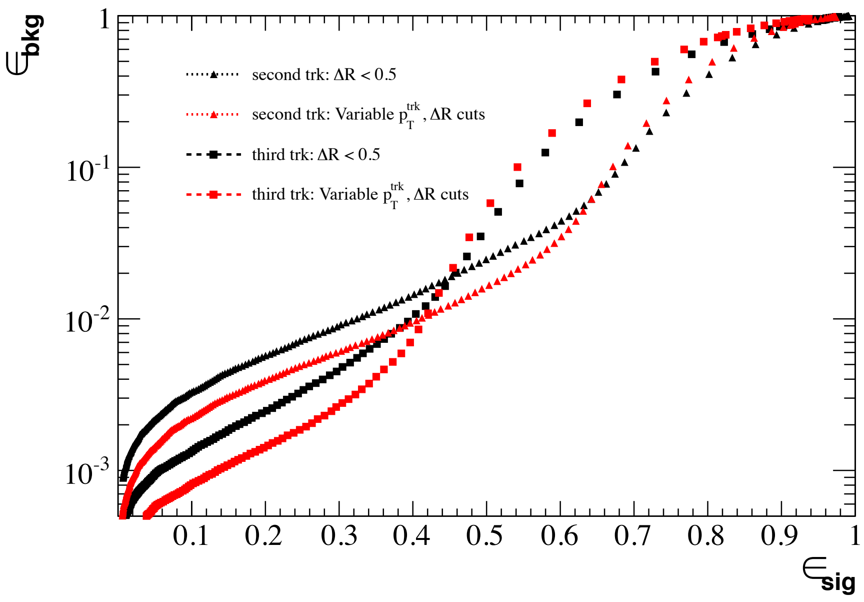
Operation points with mistag rate @ 10%, 1%, 0.1%

- Multiple ways to measure b-tag/mistag efficiency
  - Using multijet and ttbar events
  - Different measurements are combined based on weighted mean



b jet identification

- Currently available taggers are optimized for b jets from top quark decays
  - More improvements for identification b jets at high p_T
    - Study characteristics of B-hadron decays: momentum and spatial separation of tracks from B hadron



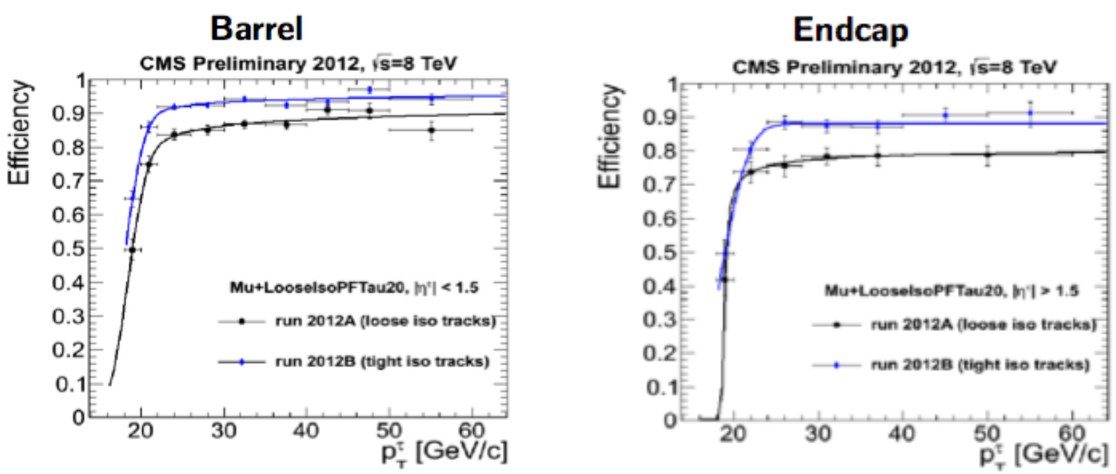
Mistag rate = 1%		
	ϵ_{TCHE}	ϵ_{TCHP}
Default	32%	40%
Modified	41%	44%
Improvement	28%	10%
Mistag rate = 0.1%		
	ϵ_{TCHE}	ϵ_{TCHP}
Default	0.9%	5%
Modified	2.5%	14%
Improvement	178%	133%

Hadronic τ (τ_h)

- ~65% of τ leptons decay hadronically (τ_h)

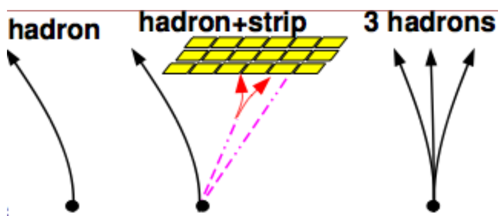
Decay Mode	Resonance	Mass, MeV/c^2	Branching ratio, %
$\tau \to h^- \nu_\tau$			11.6%
$\tau \to h^- \pi^0 \nu_\tau$	ρ	770	26.0%
$\tau \to h^- \pi^0 \pi^0 \nu_\tau$	a1	1200	10.8%
$\tau \to h^- h^+ h^- \nu_\tau$	a1	1200	9.8%
$\tau \to h^- h^+ h^- \pi^0 \nu_\tau$			4.6%
Total			63.1%
Other hadronic decays			1.7%

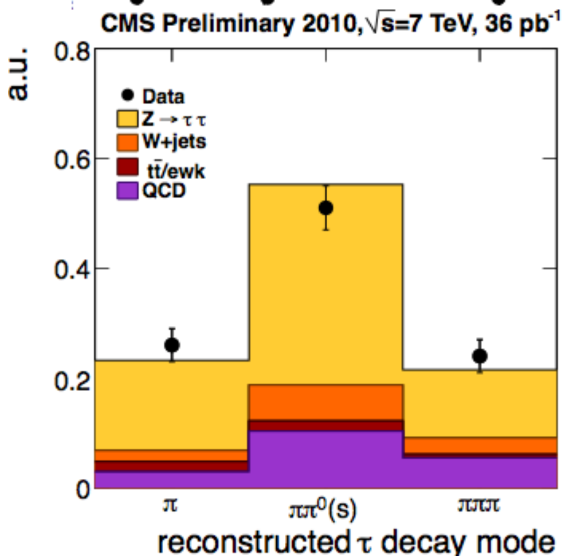
- Important to be able to select tau candidates at trigger level
  - Narrow jet with at least one energetic track close to jet axis
  - Veto on tracks in annulus around the leading track
- To allow low p_T threshold hadronic τ together with another object (electrons, muons, τ_h, or missing transverse energy) is required

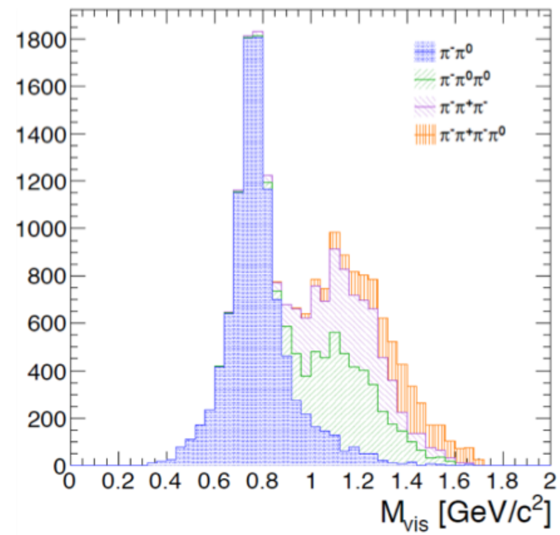


Identification of τ_h

- Using Hadrons Plus Strips algorithm
  - Reconstruct intermediate decay products
  - τ_h are reconstructed in decay modes of 1prong+0,1,2 π^0, 3 prongs



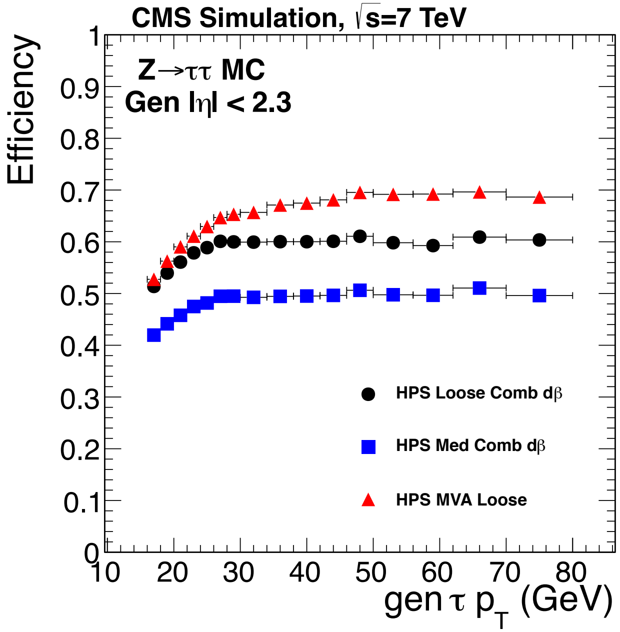


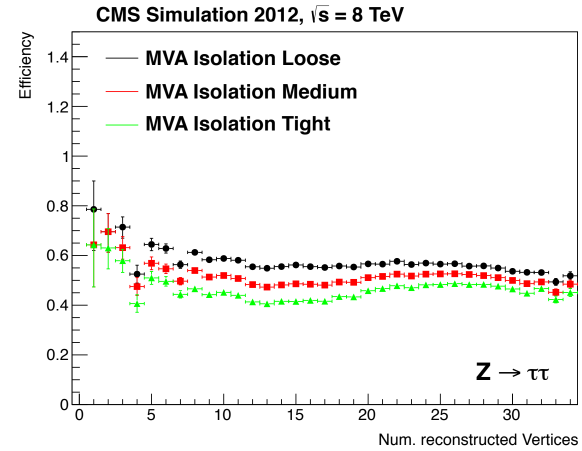


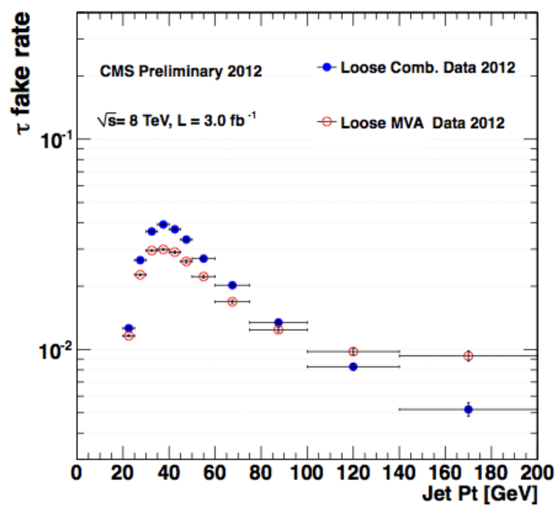
- Vertex of the leading track is assigned to τ_h
- Using isolation to discriminate against jets
  - Combined charged and neutral PF isolation within cone of 0.5
  - Multivariate isolation
  - Contribution from pileup is subtracted

Identification of τ_h

- Efficiency is measured in data and simulation using $Z \rightarrow \tau\tau$ in $\tau_h \mu$ decay mode
  - Uncertainty on τ_h ID is 7-8%



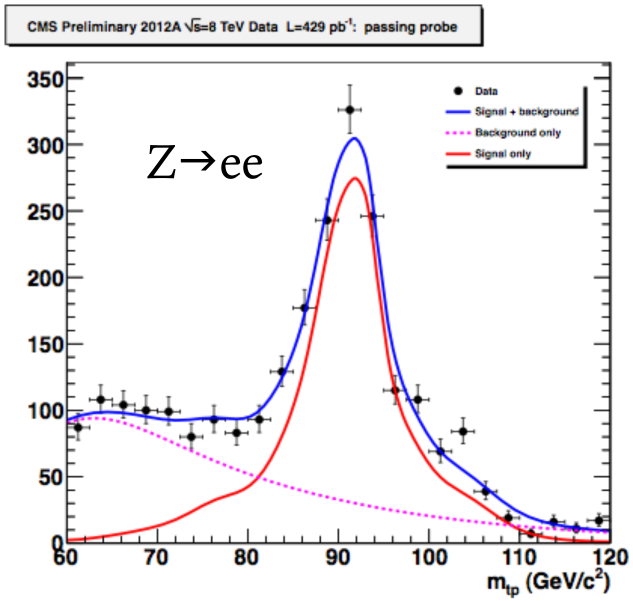




- Misidentification rate is measured in multi-jet data events

Identification of τ_h

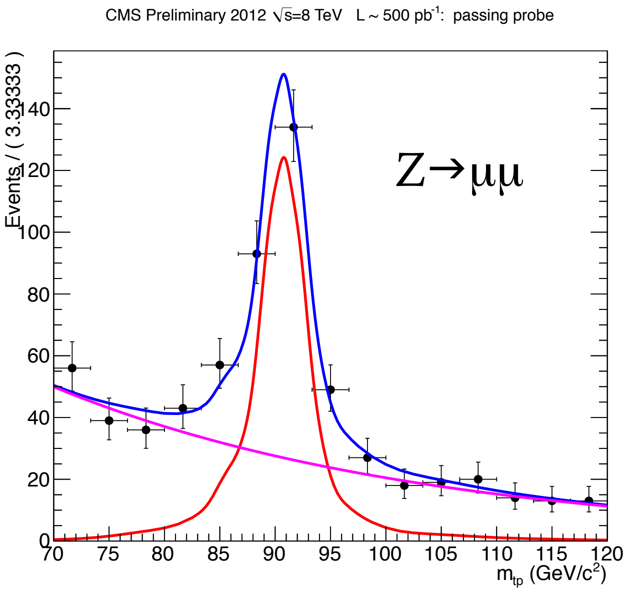
- Discrimination against light leptons:
  - Inverted electron isolation requirement or MVA approach is used to reject electrons misidentified as τ_h
  - τ_h leading track should neither match to segments in muon system nor be reconstructed as loose muon to reject muons misidentified as τ_h



Using Z→ll events

Electron fake rate is ranging 1-15% depending on working point and pseudorapidity

Muon fake rate is ~0.25%

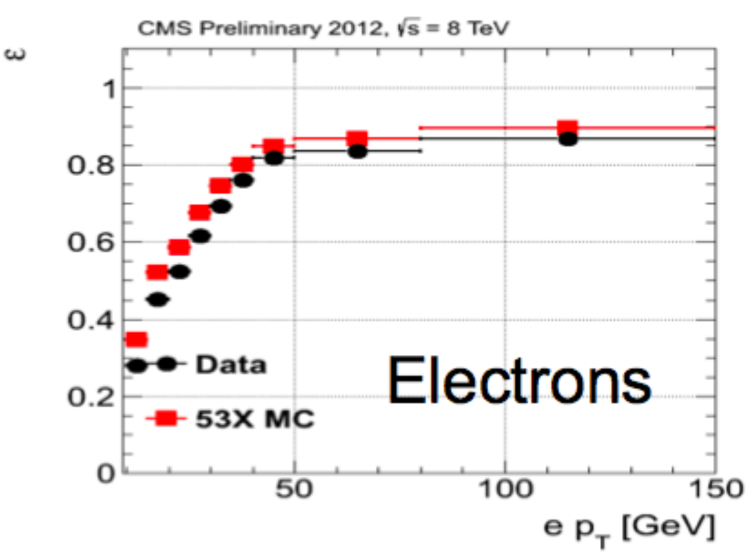


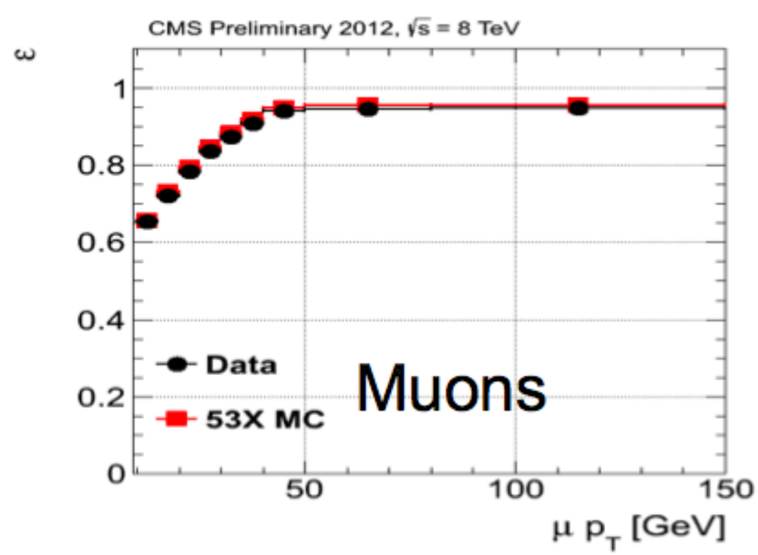
Identification of light leptons

- Electrons are identified with cut based or multivariate approach
- Muons are identified using cut based approach

Electrons
- *Match of track to cluster*
- *Track quality*
- *Shower shape*
- *Isolation*
- *Conversion rejection*

Muons
- *Global track*
- *Sufficient number of pixel hits and hits in muons stations*





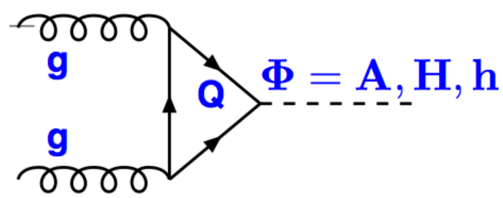
Search for MSSM $\Phi \rightarrow \tau\tau$

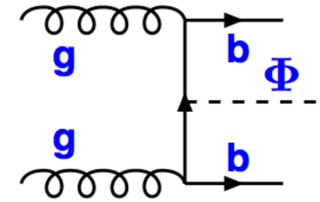
Phys. Lett. B 713 (2012) 68 – 7 TeV results

http://cds.cern.ch/record/1493521?ln=en -- 7&8 TeV results

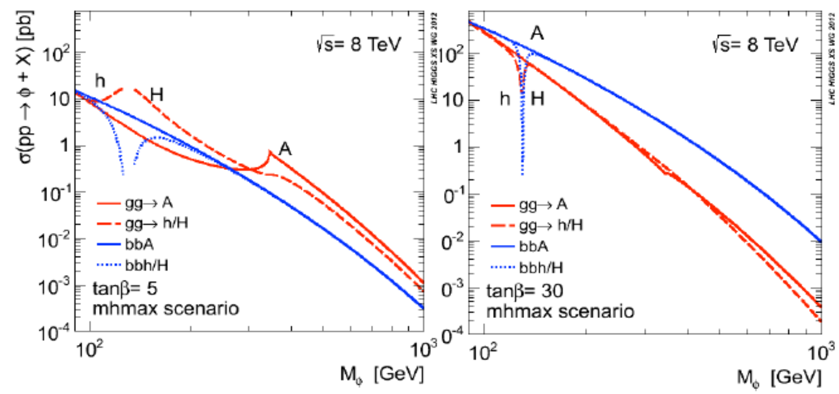
Higgs in MSSM

- Two Higgs doublets in MSSM
  - Five physical states: h, H, A, $H^{\pm}$
  - Two free parameters at tree level: $\tan\beta$ and m_A
  - For large $\tan\beta$ branching fraction to τ leptons and b quarks is enhanced





- Two production mechanisms
  - For large $\tan\beta$ either H≈A or h≈A
  - Contribution from all three states is taken into account



- Results are interpreted in mh-max scenario

$$m_h \le m_Z |\cos 2\beta|$$

  - Contribution from top (stop) loops yield upper bound on h at ~135 GeV

mh-max

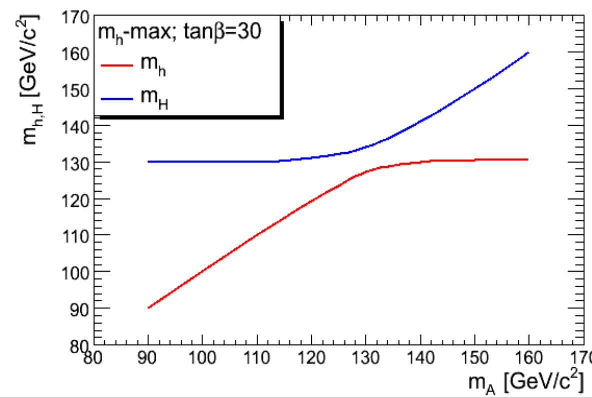
$$M_{susy} = 1TeV$$

$$X_t = 2TeV$$

$$M_2 = 200GeV$$

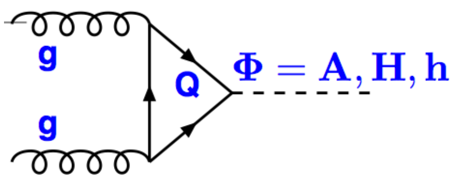
$$\mu = 200GeV$$

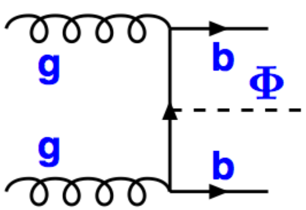
$$M_3 = 800GeV$$



Analysis strategy

- Search is performed in different final states of di-τ decays
  - e+τ, μ+τ, e+μ, and μ+μ
- To maximize the sensitivity to different productions of Higgs, the events are categorized according to number of b jets
  - No b jet
  - At least one b jet



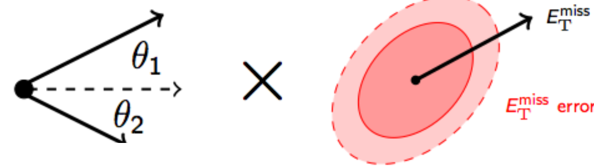


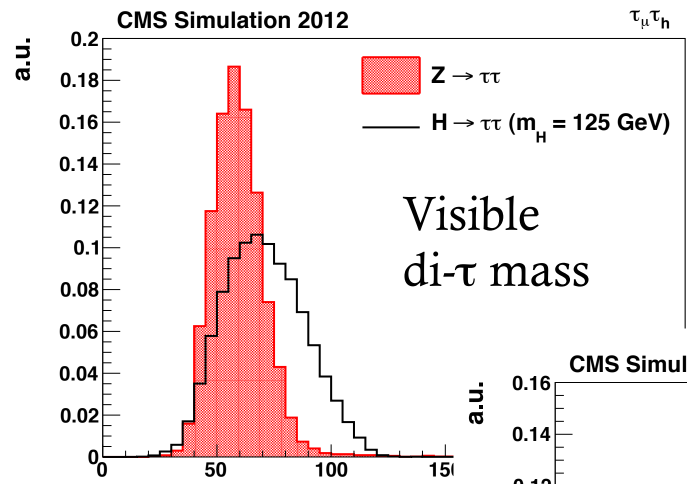
- Topological selection of di-τ signal-like events to reject major backgrounds
  - DY+jets, W+jets, ttbar, QCD
- Statistical analysis with di-τ mass spectra

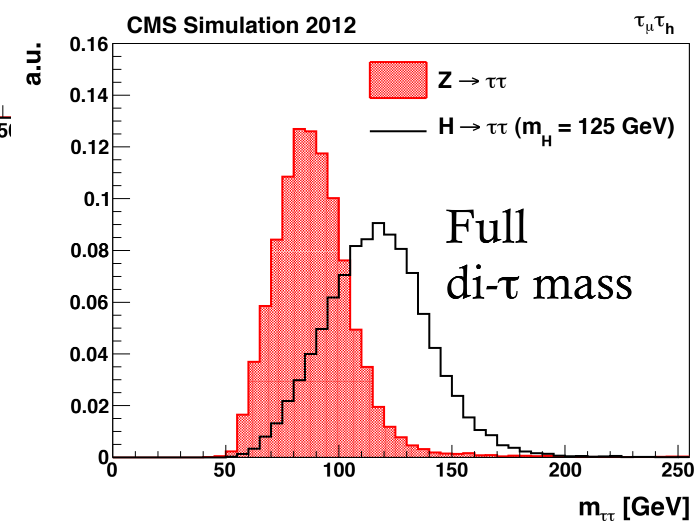
Tau pair mass reconstruction

- Uses likelihood method
  - Kinematics of tau hadronic decay products
  - Missing transverse energy and its resolution
  - → Estimates true di-τ mass per event
  - → Resolution is 15-20%

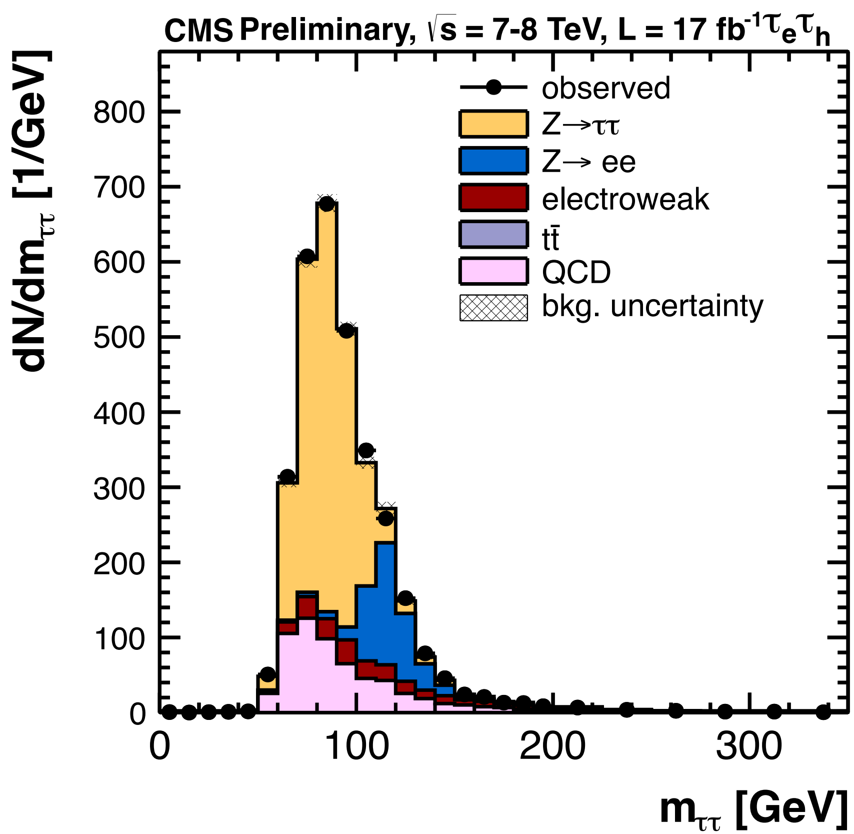
$\mathcal{L} =$







Backgrounds



e+τ mass spectrum

Irreducible Z→ττ

ttbar

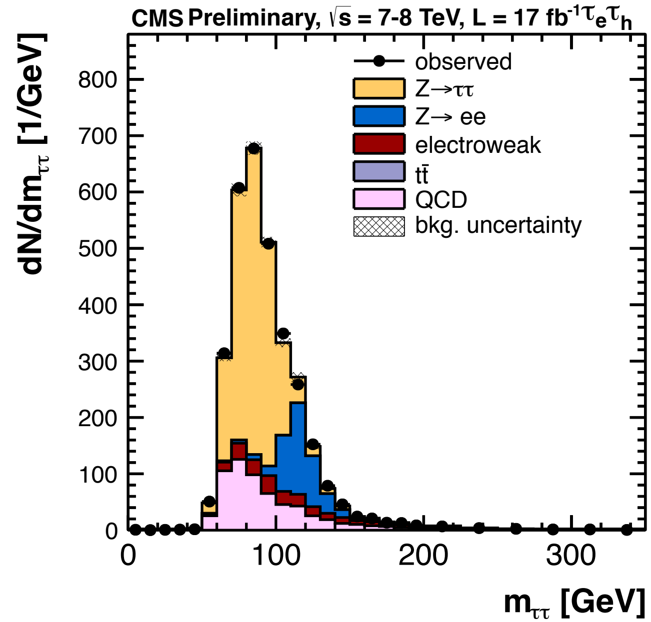
W+jets, diboson, single top

QCD

Z→ee/μμ

Backgrounds

Irreducible Z→ττ:
Using embedded sample
- **Z→μμ data events**
- **Muon is replaced with simulated tau of the same kinematics**



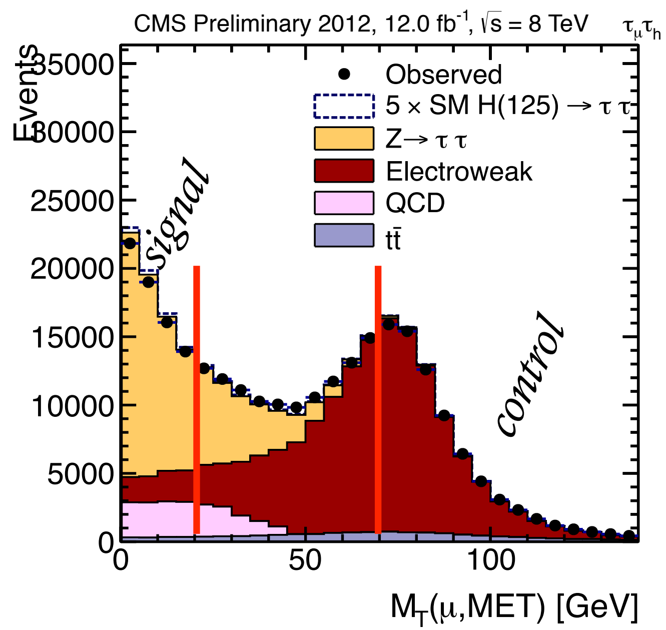
Z→ee/μμ:
Using MC simulation corrected by jet→τ and e/μ → tau fake rate

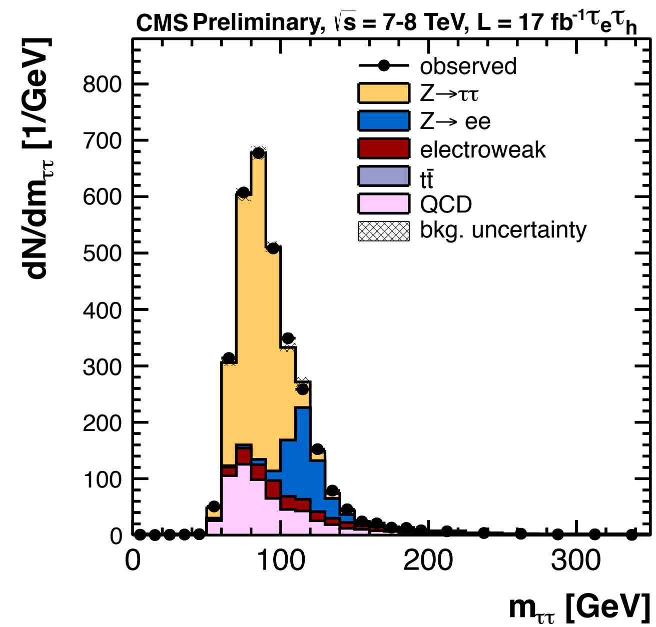
ttbar:
Using MC simulation. Normalization is checked in eμ events

Backgrounds

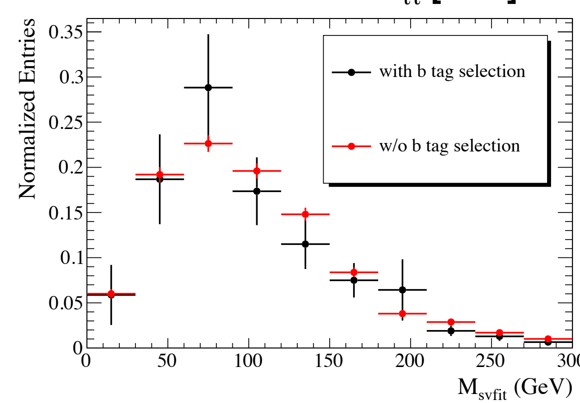
W+jets:
- Extrapolate from high m_T to low m_T region
- Mass spectrum is obtained from the simulation

diboson, single top:
Estimated from the simulation





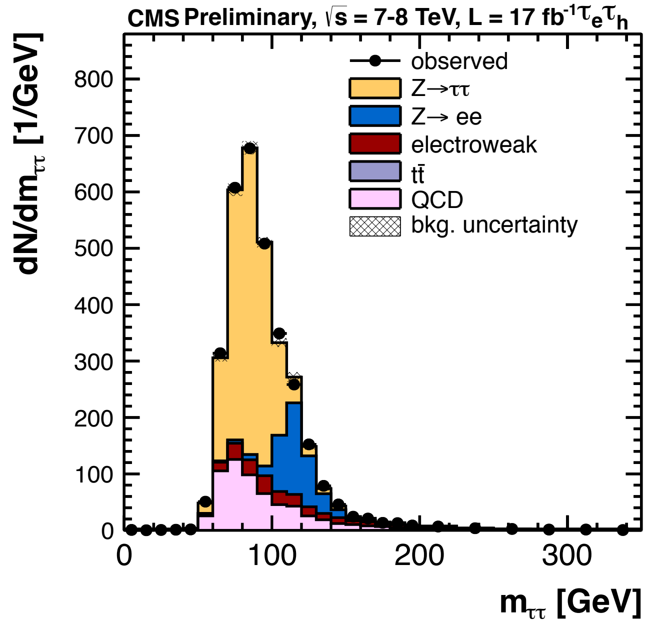
Mass distribution in b-tag category is obtained with relaxed b-tag requirement



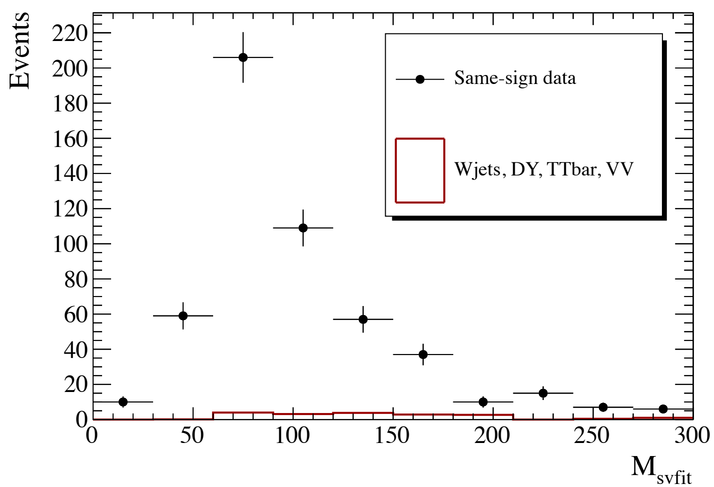
Backgrounds

QCD: Estimated fully from data

- **same-sign/opposite-sign ratio in anti-isolated data events**
- **Mass distribution is obtained from SS events with anti-isolated muons**



Btag category



$$N_{QCD} = \frac{N^{OS}_{anti-iso}}{N^{SS}_{anti-iso}} (N^{SS,data}_{iso} - N^{SS,MC}_{iso})$$

SS anti-isolated data events are dominated with multijet events in both no-bjet and bjet categories

Systematic uncertainties

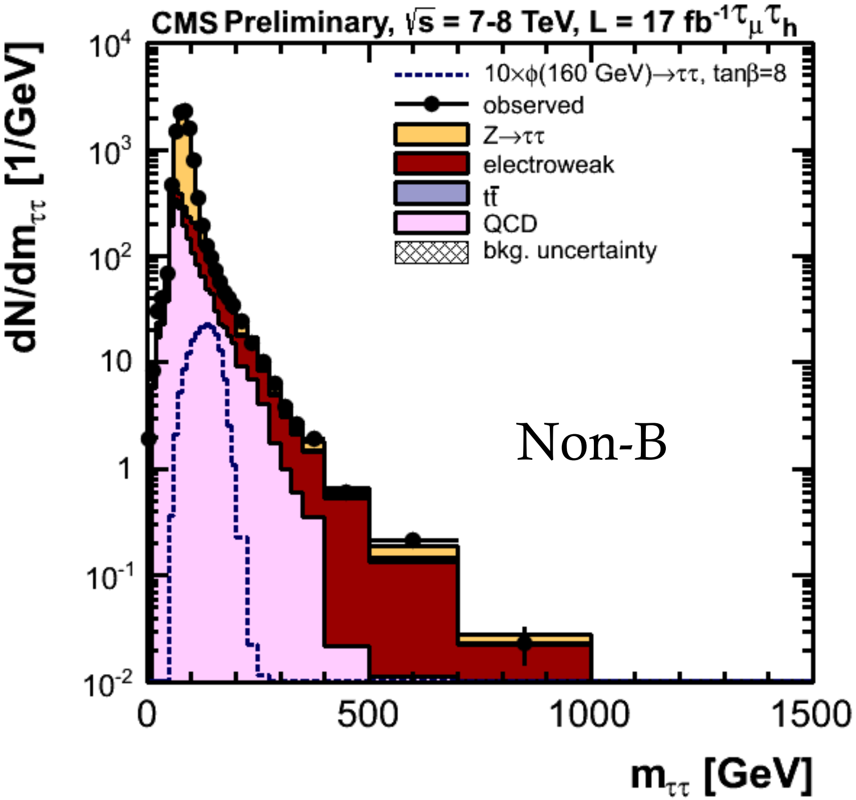
Source	actual value	No-BTag	BTag
Luminosity (Signal & VV)	2(4)%	2(4)%	2(4)%
Muon Id & Trigger	2%	2(4)%	2(4)%
Electron Id & Trigger	2%	2%	2%
Tau Id & Trigger	8%	8%	8%
JES	2.5-5%	1%	5-10%
b-tagging efficiency / jet	10%	2%	5-10%
mistag rate / jet	30%	2%	2%
TTbar Norm.	10-20%	10%	15-20%
EWK Norm.	10-30%	10-30%	10-30%
$Z \rightarrow \tau\tau$ Norm.	3%	3%	5%
QCD (Fakes) Norm.	10-20%	10%	20%
Norm. Z : lepton fakes tau	20-30%	20-30%	20-30%
Norm. Z : jet fakes tau	20%	20%	20%
Electron energy scale	1.5(2.5)%	shape altering unc.	
Tau energy scale	3%	shape altering unc.	

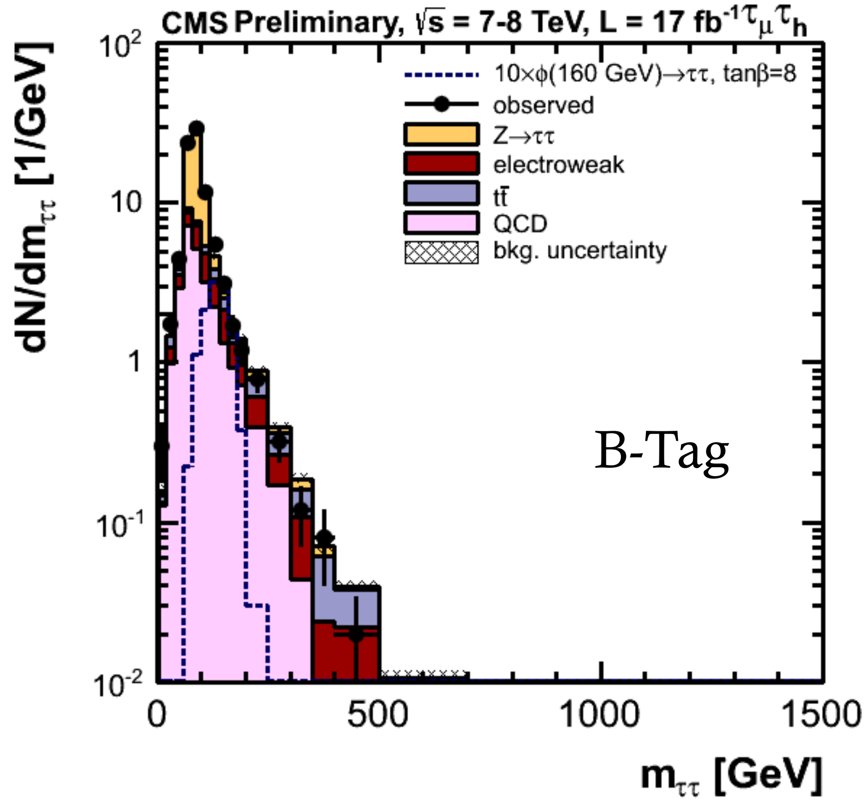
theory uncertainty	value
μ_r / μ_f ($bb\phi$)	5 – 25 %
μ_r / μ_f ($gg\rightarrow\phi$)	8 – 15 %
PDF + α_S	2 – 10%
UE & PS	4%

Mass spectra

- Full di-τ mass in two channels and two categories

$\mu + \tau$

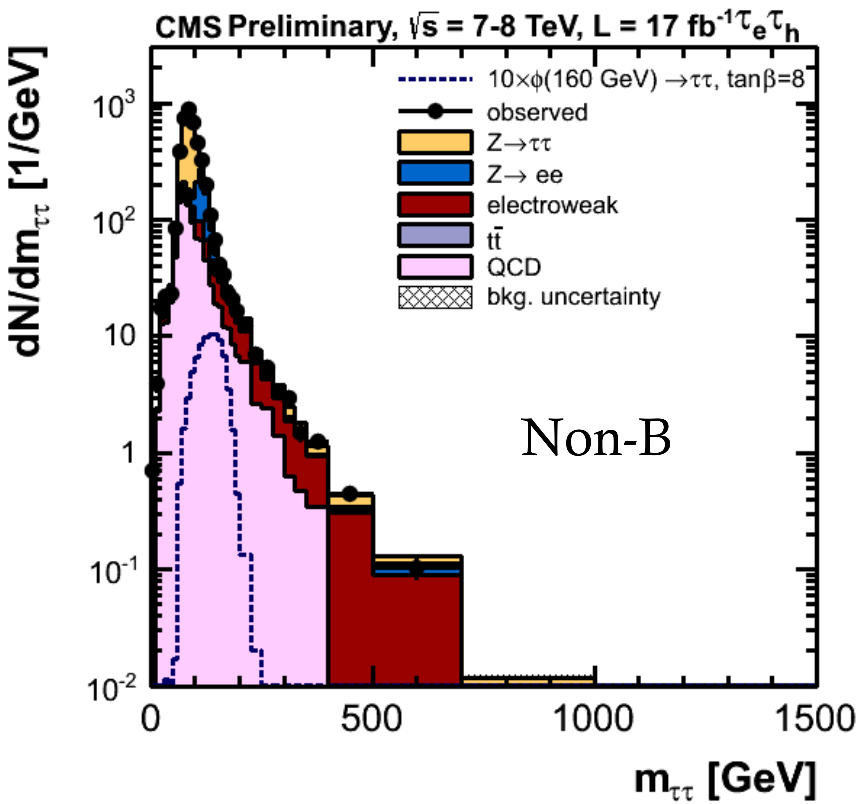


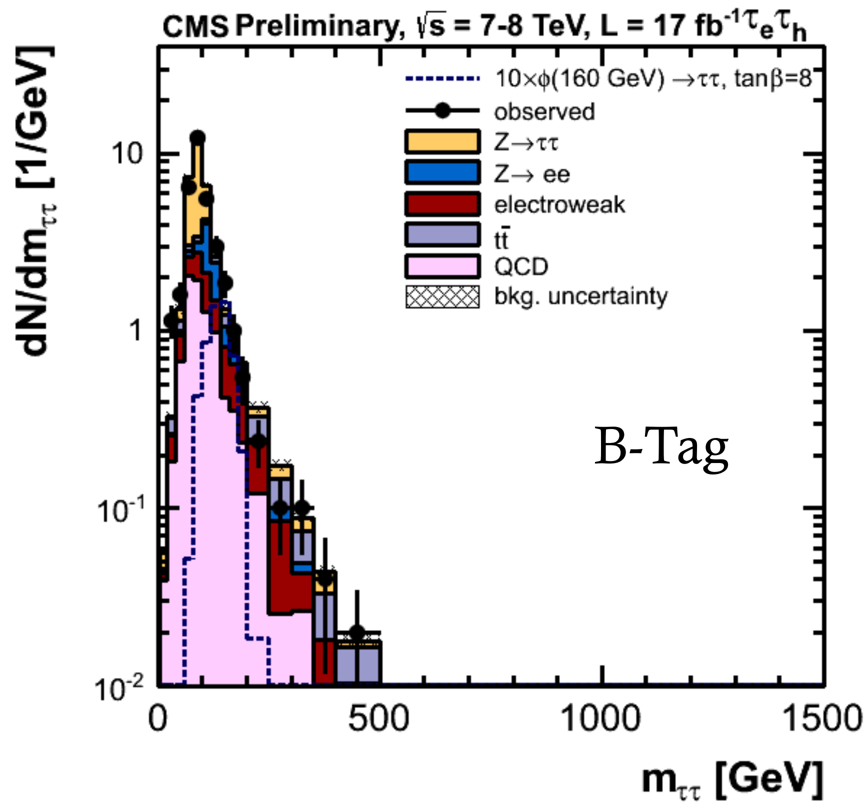


Mass spectra

- Full di-τ mass in two channels and two categories

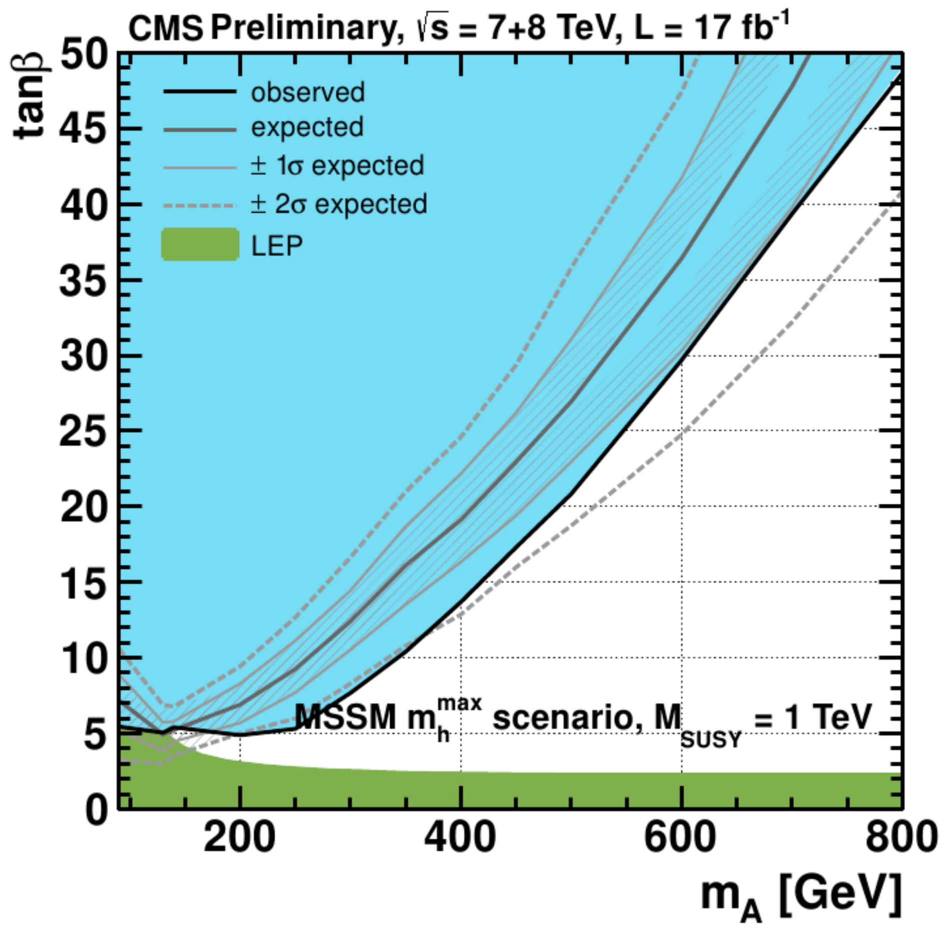
$e + \tau$





Results

- No evidence of $\Phi \rightarrow \tau\tau$ was found
  - Combining four channes $e+\tau$, $\mu+\tau$, $e+\mu$, and $\mu+\mu$
  - Limits are set within mh-max scenario on $\tan\beta$ vs. m_A plane

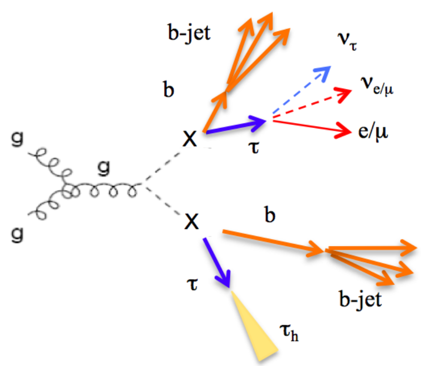


Search for third-generation leptoquarks and top squarks

http://arxiv.org/abs/1210.5629 -- 7 TeV results
accepted by PRL

Motivation

- Symmetries between leptons and quarks motivate boson fields mediating lepton-quark interaction
  - Suggested by GUT, composite, Technicolor, top-SU(5) models
- New scalar or vector bosons, leptoquarks, are predicted
  - Fractional electric charge and non-zero lepton and baryon numbers
  - Decay to the lepton and quark from the same generation with model-dependent branching fraction
- Dominant production of pair of LQ is via QCD interactions
  - Cross section depends only on mass of LQ



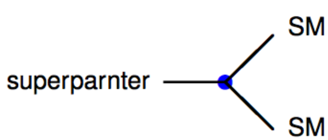
- Pair production of third generation scalar LQ are studied
  - Signature with two τ leptons and two b jets: $e\tau_h$+2bjets and $\mu\tau_h$+2bjets

Motivation

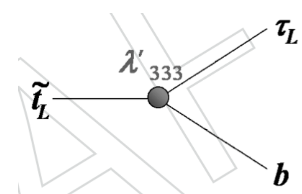
- Symmetries between leptons and quarks motivate boson fields mediating lepton-quark interaction
  - In SUSY R-parity violating models mediator is top squark
  - For heavy gluino scenario stop and LQ pair production cross sections are very similar
- R-parity

$$R_p = (-1)^{3B+L+2S}$$

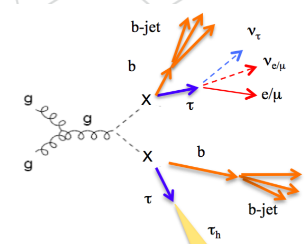
  - R-parity conservation: B and L number conservation, DM candidate
  - R-parity violation: LPS decays



$$W = \frac{1}{2}\lambda_{ijk} L_i L_j E^c_k + \lambda'_{ijk} L_i Q_j D^c_k + \frac{1}{2}\lambda''_{ijk} U^c_i D^c_j D^c_k$$



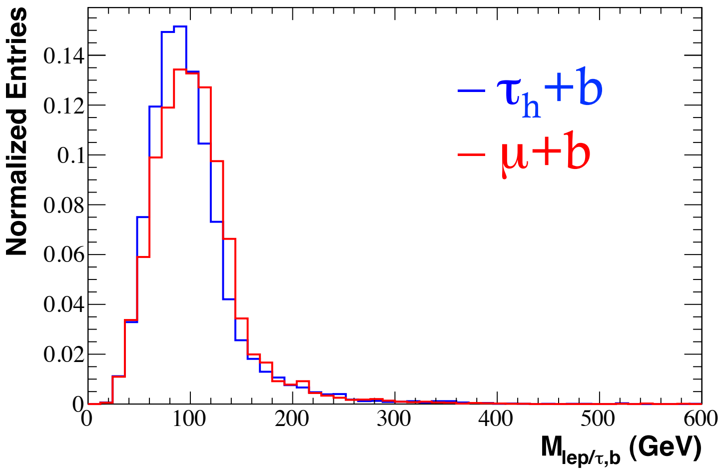
- In case of lepton-number violating coupling λ'_{333} stop decays to τ lepton and b quark
  - The same final state: $e\tau_h$+2 bjets and $\mu\tau_h$+2 bjets

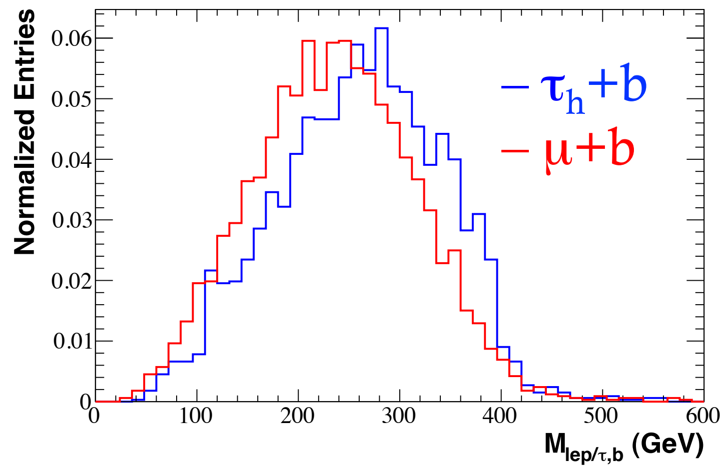


Sensitive observables

- To improve signal sensitivity
  - Invariant mass of τ_h and b jet

$$M = \sqrt{(E_{\tau_h} + E_b)^2 - (\vec{p}_{\tau_h} + \vec{p}_b)^2}$$



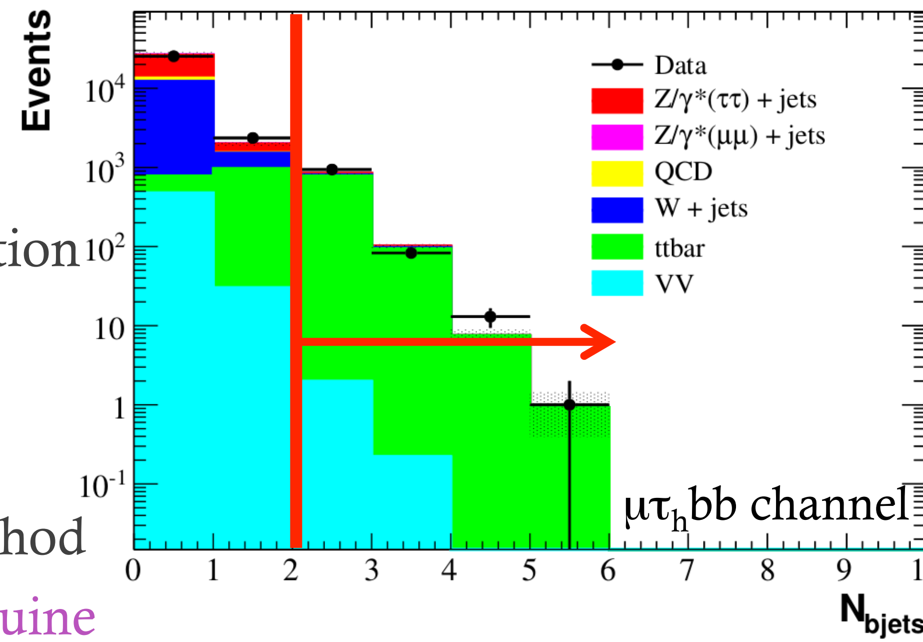


  - Use S_T distribution to check excess over the SM background prediction

$$S_T = p_T(l) + p_T(\tau_h) + p_T(bjet1) + p_T(bjet2)$$

Backgrounds

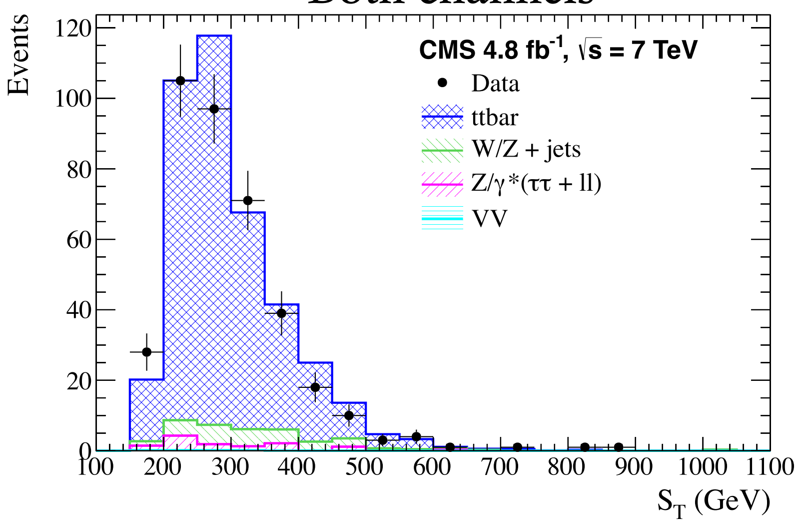
- Select events with light high-p_T lepton, τ, and two b jets
- Backgrounds
  - ttbar production – major bkg.
    - Control shape and normalization in sample with low $M(\tau_h,b)$
  - Background due to false τ_h – W/Z+jets, QCD (small)
    - Estimated using fake rate method
  - $Z(\tau\tau/ee/\mu\mu)$+jets, when τ_h is genuine or misidentified from lepton
    - Estimated from MC simulation
  - Diboson processes estimated from MC
    - 30% uncertainty due to precision of VV cross section measurement



ttbar background

- ttbar normalization and shape is checked in sample rejected by $M(\tau_h, b)$ cut

Both channels



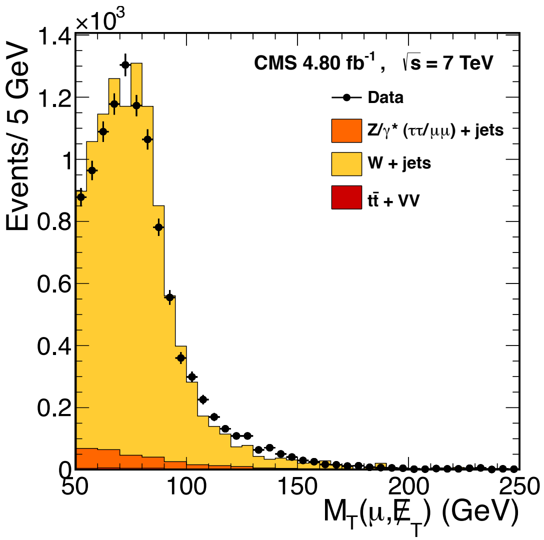
$\mu\tau_h bb$ channel

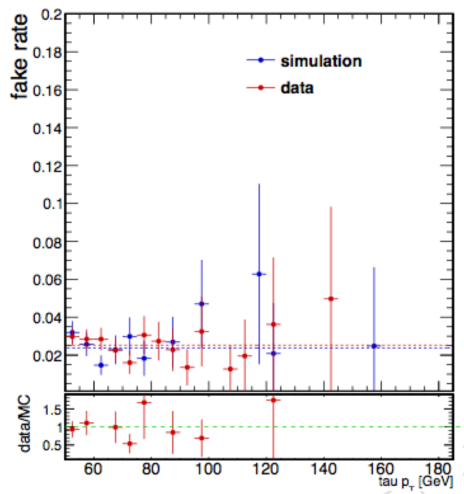
process	yield
$t\bar{t}$	$270 \pm 7.4 \pm 29.7$
W+jets/Z+jets	$15.3 \pm 0.9 \pm 3.8$
$Z \to \tau^+\tau^- / \ell^+\ell^-$	$7.5 \pm 1.8 \pm 0.5$
EWK	$0.43 \pm 0.08 \pm 0.13$
Total Bkg.	$293 \pm 7.6 \pm 29.9$
Data	279
Signal 350	7.25 ± 0.63

- Good agreement on normalization and S_T shape
  - Yields larger uncertainty (13%/17%) than one from CMS measurement on $\mu\tau_h bb/e\tau_h bb$ channels

W/Z+ jets background

- Measure jet→τ_h misidentification rate





In MC

$fr = 2.22\% \pm 0.5\%$

In data

$fr = 2.44\% \pm 0.5\%$

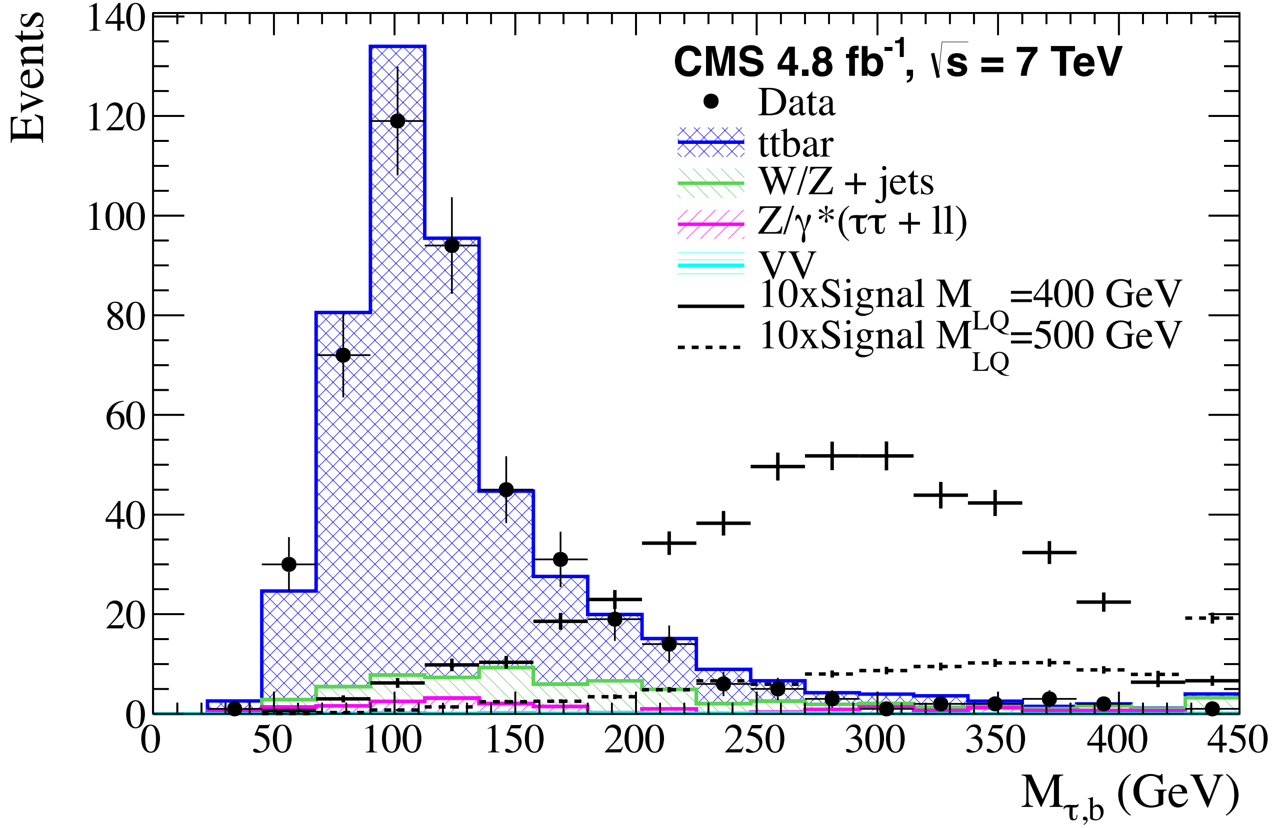
Use same-sign lepton+non-iso. τ_h events from W+1jet production

	from simulation
W + jets	93±17
Z + jets	97±7 (only fake τ from MCTruth)
total bkg.	190±24 (stat.)
	from fake rate method
total bkg.	161±3 (stat.)±30 (syst.)

- Select events with anti-isolated τ_h ($N_{anti\text{-}iso}$)
- Use $N_{fake} = \dfrac{fr}{1-fr} N_{anti-iso}$ to obtain the background yield

$M(\tau_h,b)$ distribution

- $M(\tau_h,b)$ before applying cut
  - Both channels combined

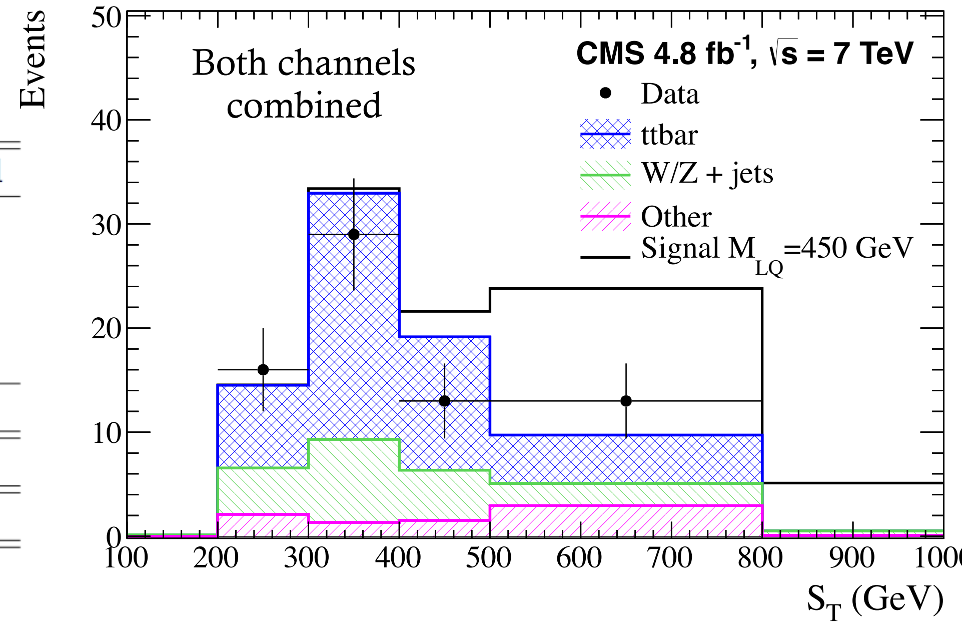


Final distribution and yields

- S_T distribution after final selection $M(\tau_h, b) > 170$ GeV

	$\mu + \tau_h b\bar{b}$ channel	$e + \tau_h b\bar{b}$ channel
$t\bar{t}$	$38.1 \pm 3.4 \pm 4.9$	$10.9 \pm 1.8 \pm 1.4$
W+jets/Z+jets	$11.6 \pm 0.1 \pm 2.6$	$8.4 \pm 0.1 \pm 1.8$
$Z(\tau\tau/ll)$	$5.0 \pm 1.6 \pm 2.1$	$2.1 \pm 1.5 \pm 0.9$
Diboson	$0.5 \pm 0.1 \pm 0.2$	$0.3 \pm 0.1 \pm 0.1$
Total Background	$55.2 \pm 5.2 \pm 8.4$	$21.8 \pm 3.5 \pm 3.6$
Data	46	25
Signal (450GeV)	$13.2 \pm 0.3 \pm 0.9$	$8.4 \pm 0.2 \pm 0.6$

Source	Value
Tau ID	6 %
b mistag rate	10%
ttbar norm.	17% / 13%
W/Z+jets	30%
Z(ll)+jets	70% / 30%
JER/τ ER	10%

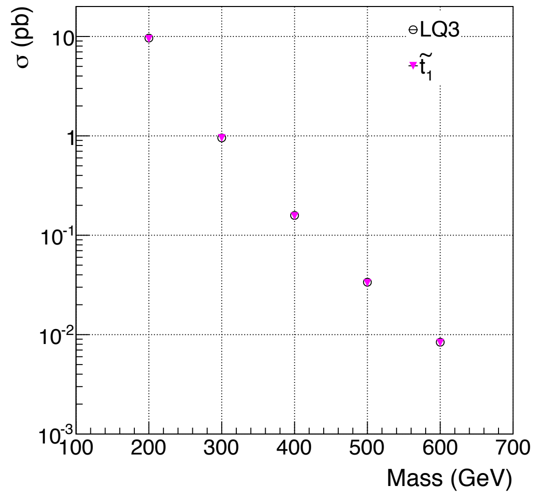


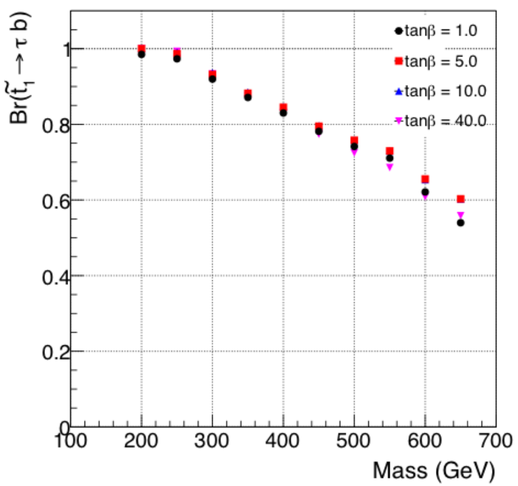
Uncertainties on signal modeling

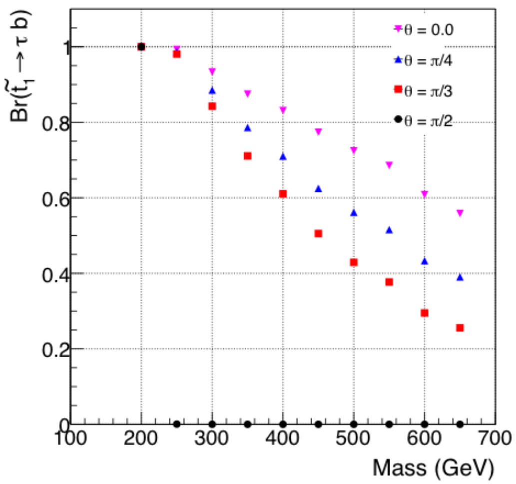
Source	Value
FSR/ISR	4%
PDF unc. on σ	10-30%
PDF unc. on acceptance	1-3%

Stop vs LQ

- Cross sections agree within couple of percent for heavy gluino scenario
  - Dependence on tanβ and stop mixing angle is small
- Branching fraction is strongly dependent on various parameters: SU(2) gaugino mass M_2, Higgsino mixing parameter μ, tanβ, stop mixing angle etc.







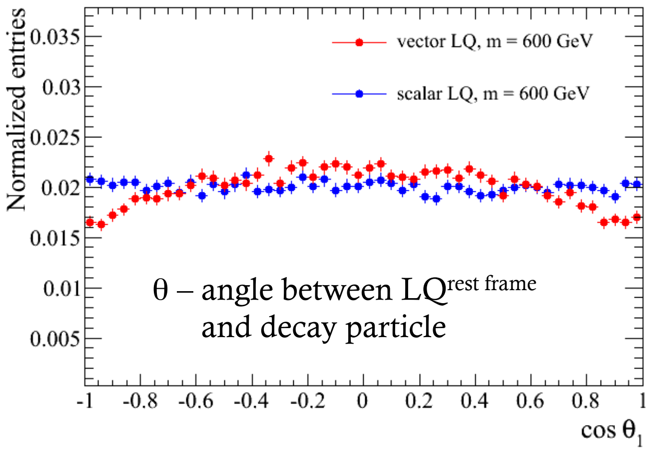
Results are interpreted in heavy gluino mass limit, assuming:

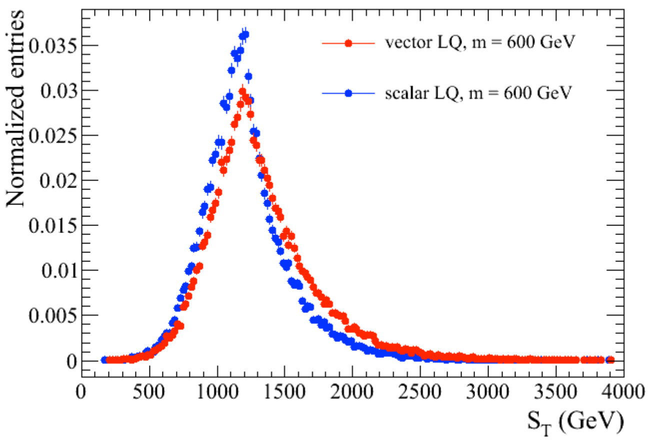
- heavy or light μ and M_2
- tanβ ~ 40
- Stop mixing angle ~0

Vector LQ vs scalar LQ

- Kinematics and decay angles from vector are expected to differ from those of scalar LQ
  - No preferred direction of decay particles for SLQ
  - VLQ decay products tend to be harder

The compare VLQ and SLQ:
Models from arXiv:0502067
CalcHEP http://hepmdb.soton.ac.uk/



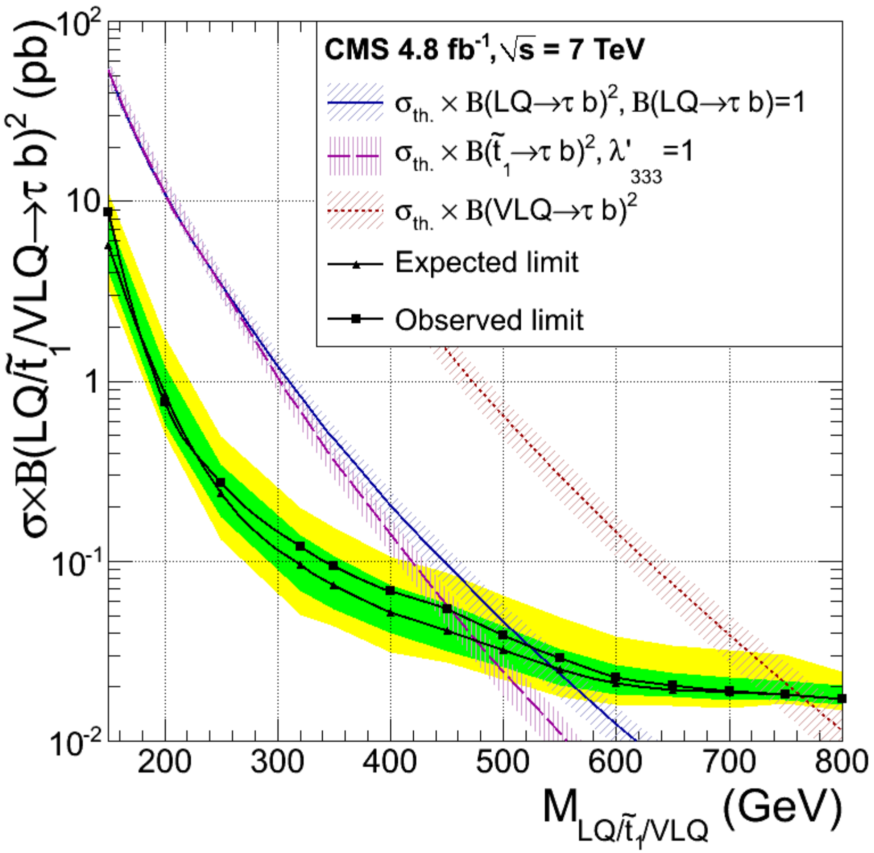


- Difference in p_T/eta distributions of final state objects is < 1%
  Difference in S_T>800 GeV spectrum is ~2%

→ Results are interpreted for vector LQ scenario

Results

- Two channels are combined taking into account correlation between systematic uncertainties



Assuming $Br(LQ \to \tau b)=100\%$, scalar leptoquakrs with mass < 525 GeV are excluded

Previous: D0 (425/pb) M(SLQ)< 210 GeV

Assuming $\lambda'_{333}=1$ and chosen benchmark, RPV stops with mass < 455 GeV are excluded

Previous: CDF (322/pb) M(stop)< 153 GeV

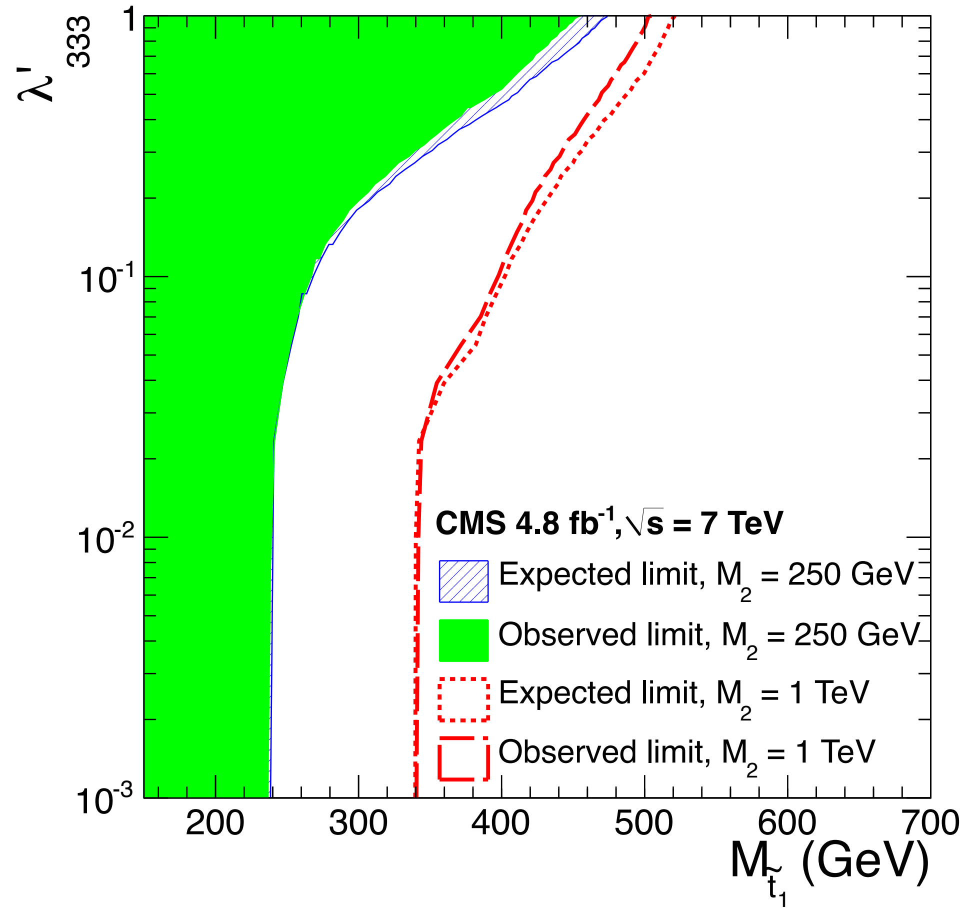
Top SU(5) vector leptoquakrs with mass < 760 GeV are excluded

→ First limits on model *arXiv:1206.0409*

limit on RPV coupling

- Top squarks with mass below 240 (340) GeV are excluded for all values of $\lambda'_{333} > O(10^{-7})$ for M_2=250 (1000) GeV

→First direct limit on λ'_{333}



Conclusion

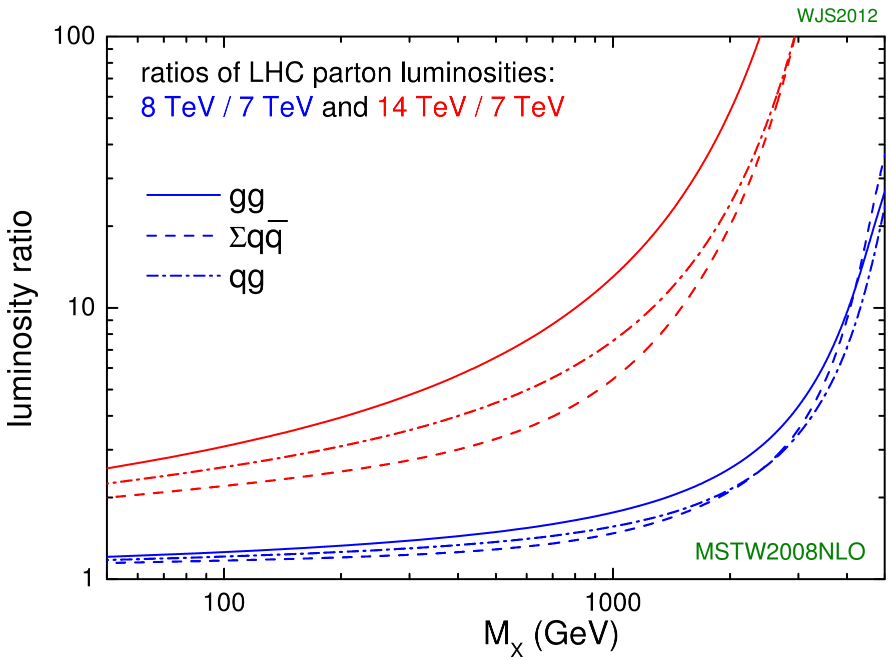
- Search for new phenomena in final states with τ leptons and b jets
  → Search for Higgs boson within minimal SUSY model
  - No excess is observed in di-τ mass spectrum
  - The most stringent limits are set in MSSM parameter space for mh-max benchmark scenario

  → Search for pair production of leptoquarks or top squarks
  - Observed distribution of S_T agrees with the SM background prediction
  - Limits are set on third-generation leptoquark pair production as well as on top squark pair production decaying within RPV scenario for a given parameter set
  - First direct bounds are obtained on RPV coupling between top squark, τ lepton, and b quark
  - Limits are set top-SU(5) model vector leptoquarks

Outlook

- No hits of new physics so far
  - Efforts are still on-going to utilize all available data at 7 and 8 TeV and improve analyses strategy

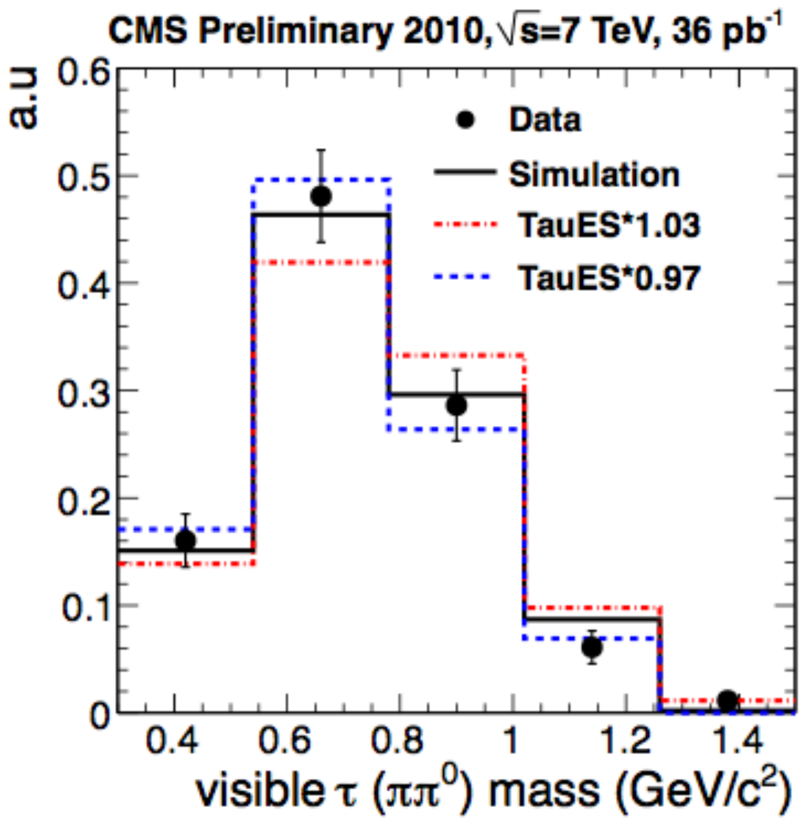
- Significant improvement is expected for high mass searches with higher CME run of LHC

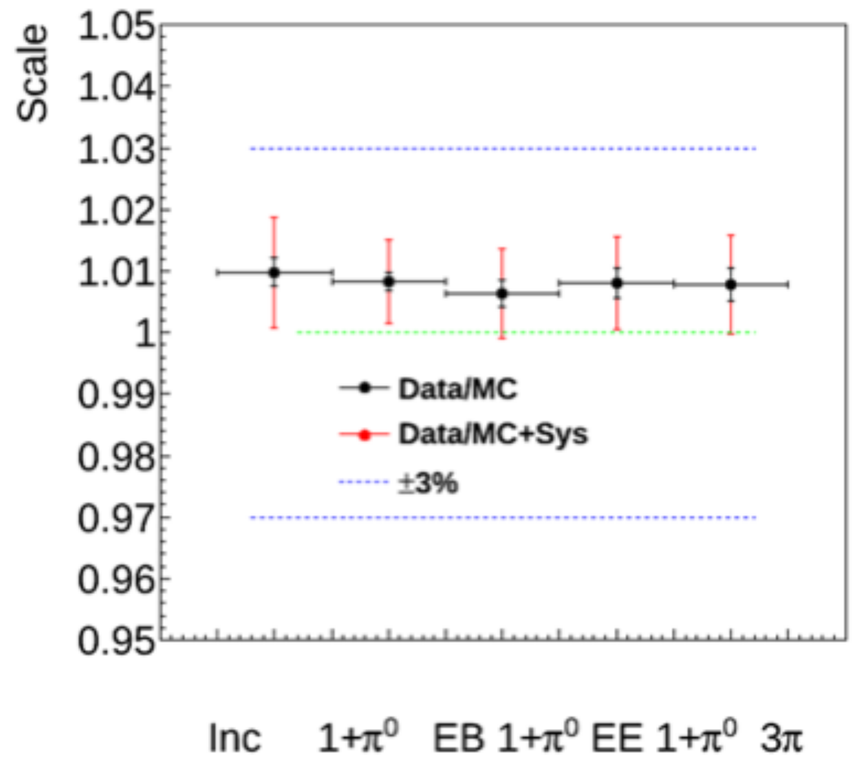


BACKUP

Tau energy scale

- Energy scale was estimated data and MC simulation



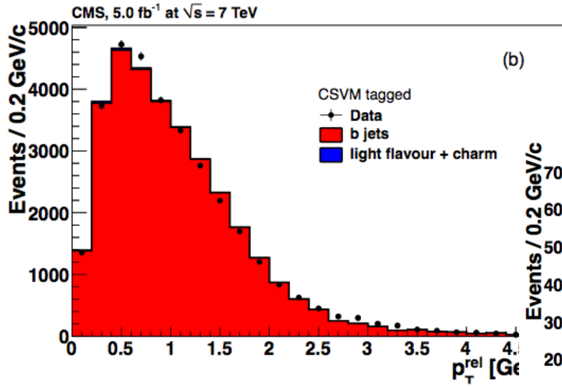


Conservative 3% uncertainty on tau energy scale

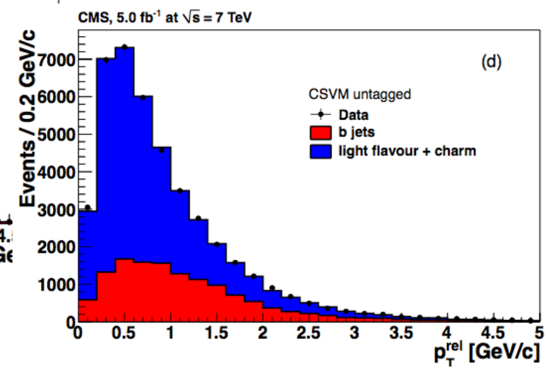
Object ID – b jets

Multiple methods are used to measure b-tagging efficiency in multijet events

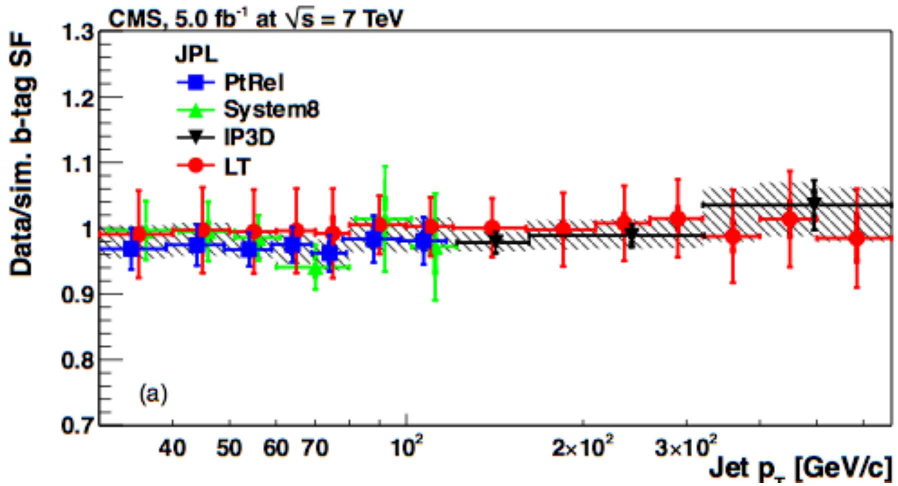
- Using relative p_T or 3D impact parameter of muons in jets to discriminate b-jets from light or c-jets
- Using lifetime tagger method on both muon-jet and inclusive jet sample



$$\varepsilon_b^{tag} = \frac{f_b^{tag} \cdot N_{data}^{tag}}{f_b^{tag} \cdot N_{data}^{tag} + f_b^{untag} \cdot N_{data}^{untag}}$$



Different measurements are combined based on weighted mean of the scale factors for jets with 30 GeV < p_T < 670 GeV

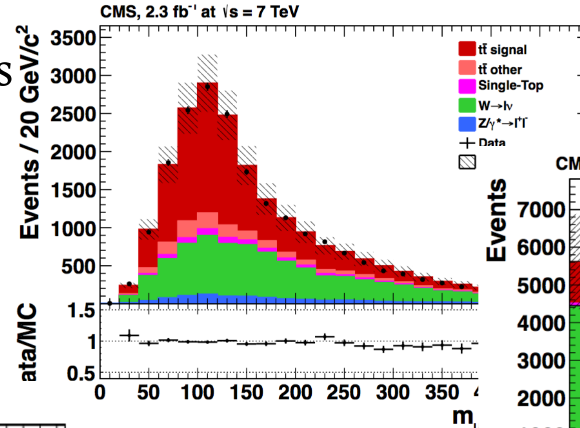


Object ID – b jets

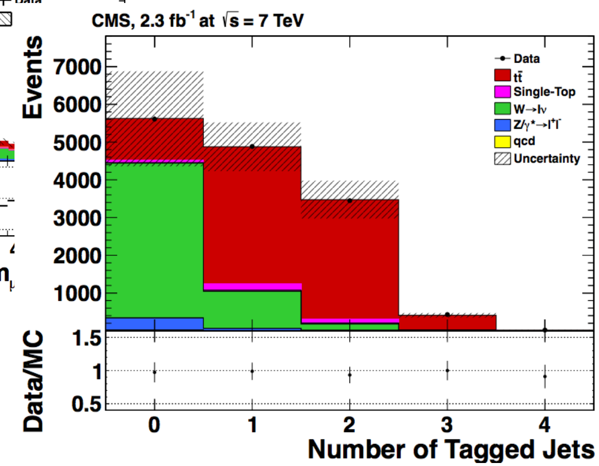
Multiple methods are used to measure b-tagging efficiency in ttbar events

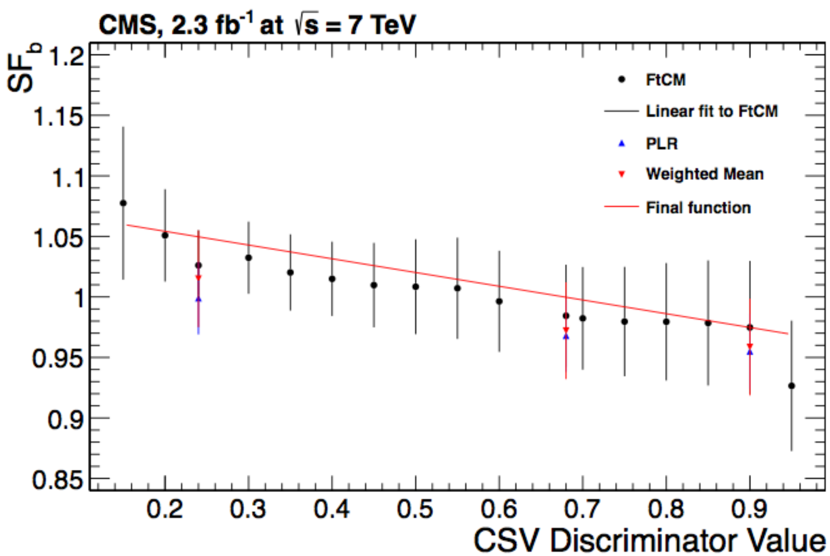
lepton+jets and dilepton+jets decays

- b-enriched jet sample
- *Flavor tag consistency method*
- *PL ratio*
- Flavor tag matching method



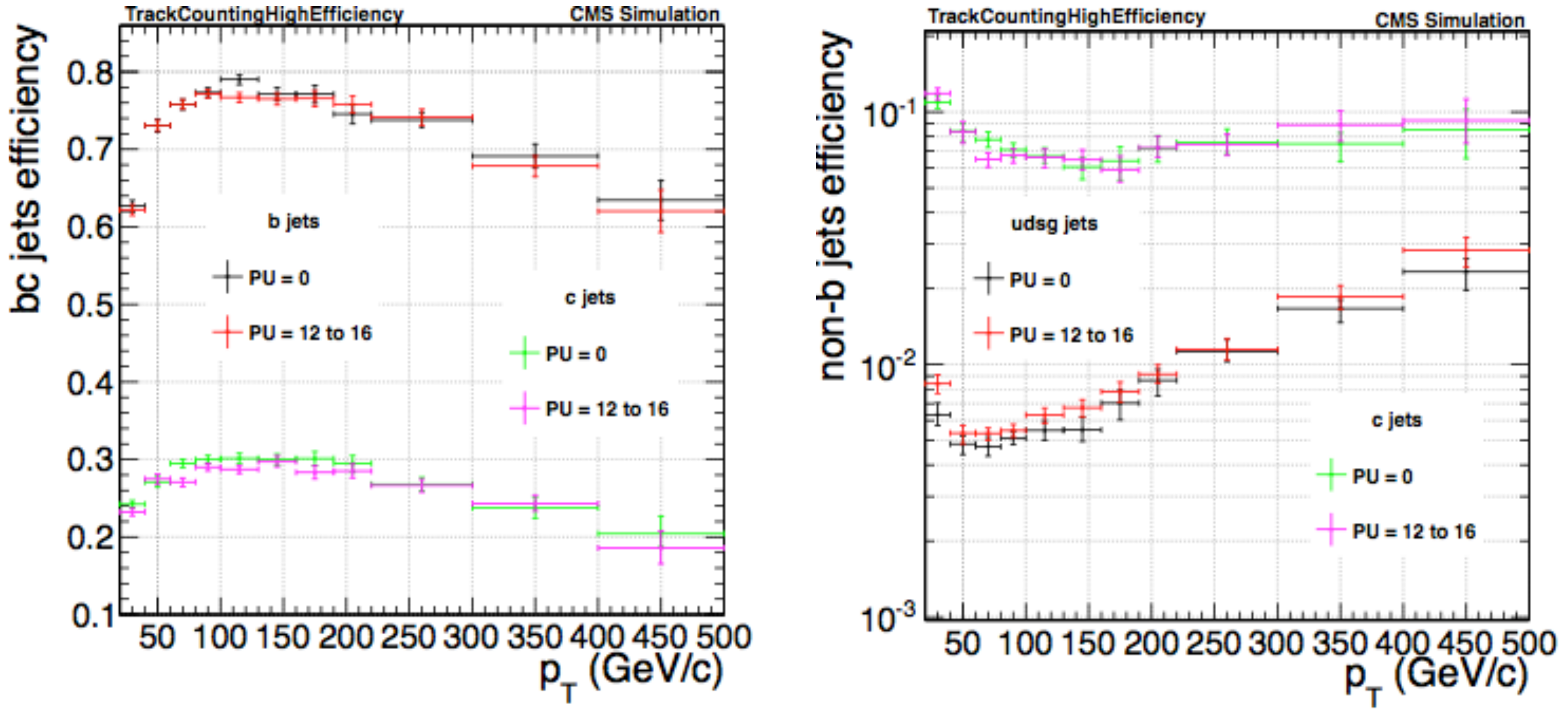
$$\hat{\Delta}_b^{enr} = \Delta_b^{enr} - F \times \Delta_b^{depl}$$





- Combined scale factor is derived as a weighted mean of scale factors from two best measurements from two samples yielding ~4% uncertainty
- Scale factor as function of discriminator value is available for MVA methods

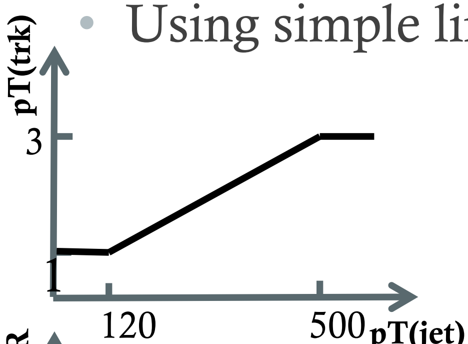
b-tagging @ high pT

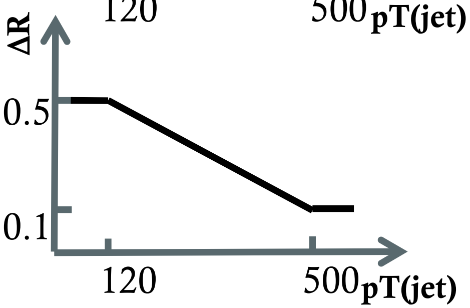


- Performance of b-tagging algorithms are optimized for medium pT range
  - At high and low pT both mistag rate goes up and efficiency degrades

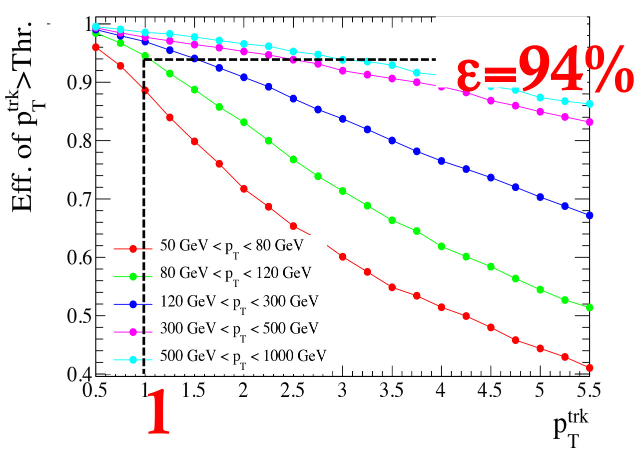
Optimization for jet-track association

- Selection for tracks assocated to jets is optimized for high pT jets – described in AN-12-019
  - Both pT(trk) and ΔR can be used to improve performance
  - Using simple linear parameterization

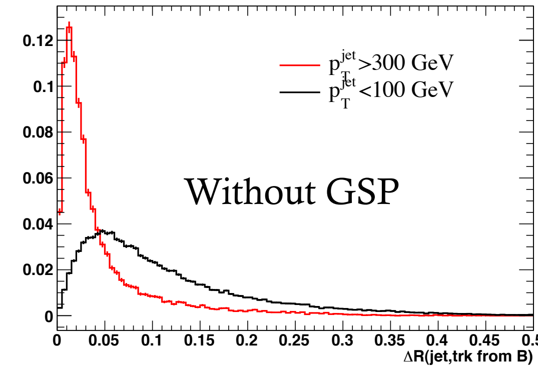


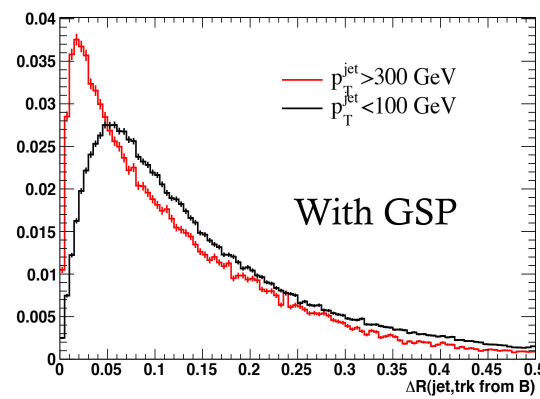


Eff of pT cut on tracks



ΔR(jet, track from B)



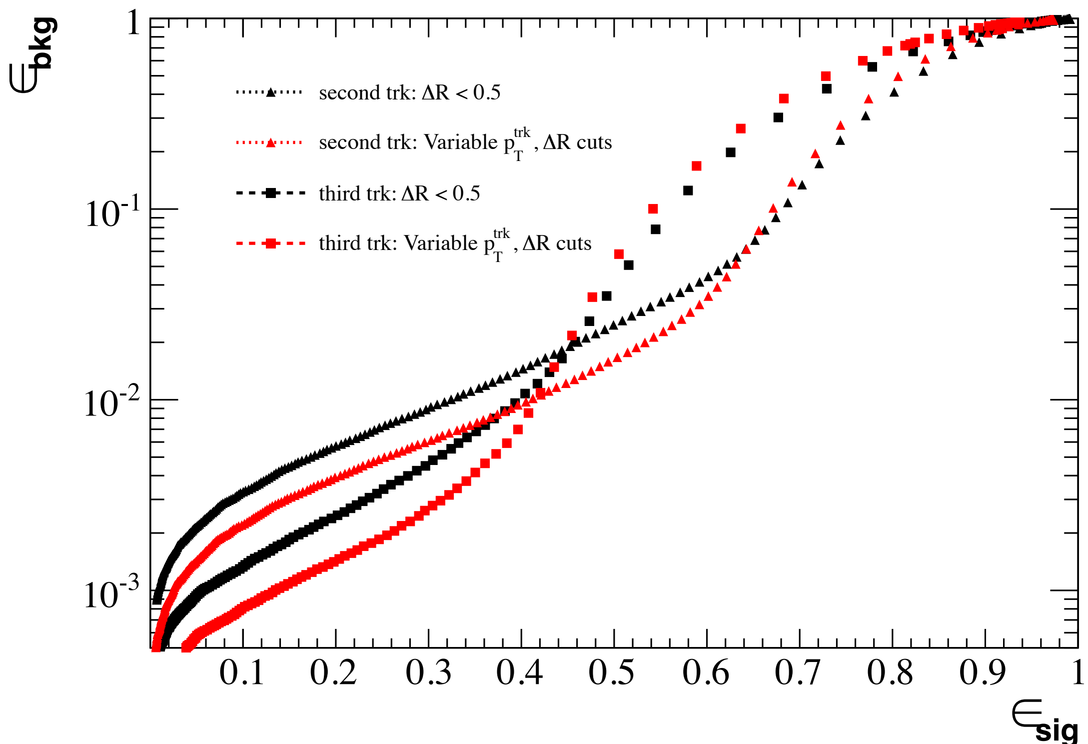


Improvements seen for physics definition of flavor

Performance

- TC-taggers

Mistag rate = 1%		
	ϵ_{TCHE}	ϵ_{TCHP}
Default	32%	40%
Modified	41%	44%
Improvement	28%	10%
Mistag rate = 0.1%		
	ϵ_{TCHE}	ϵ_{TCHP}
Default	0.9%	5%
Modified	2.5%	14%
Improvement	178%	133%



BACKUP for Higgs->ττ

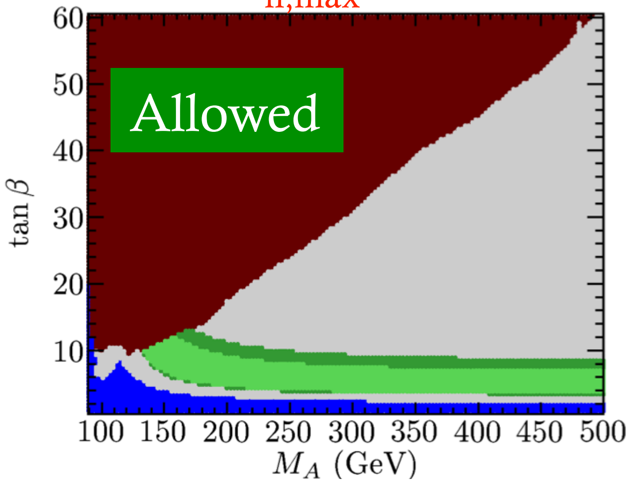
Implications of 125 GeV boson

- The main parameters in MSSM are
  - at tree level: M_A and $\tan\beta$
  - at loop level: M_{SUSY} soft-SUSY-breaking squark mass of the third generation and X_t stop mixing parameter
  - All scenarios with some degree of mixing one can get $M_h \sim 125$ GeV

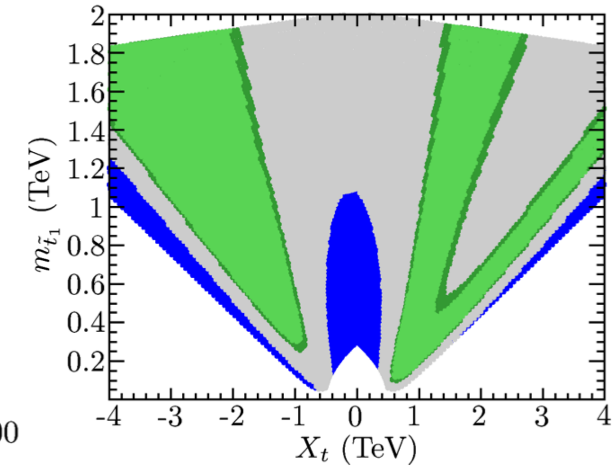
$m_{h,max}$

$$M_{susy} = 1TeV$$
$$X_t = 2TeV$$
$$M_2 = 200GeV$$
$$\mu = 200GeV$$
$$M_3 = 800GeV$$

$m_{h,max}$



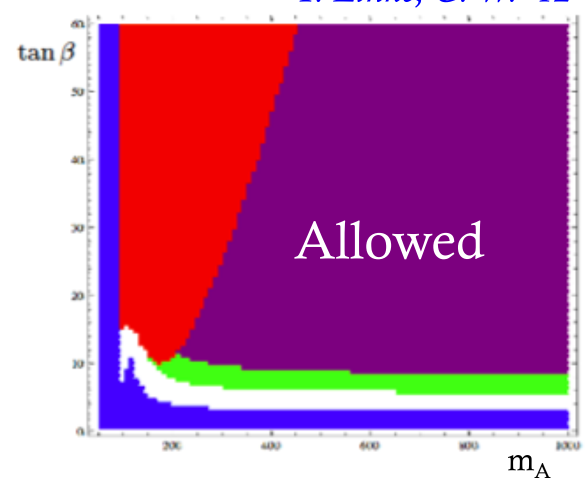
LHC limits from SM Higgs search: of $123 \text{ GeV} \lesssim M_{H_{SM}} \lesssim 127 \text{ GeV}$



Constraints on $|X_t|$ vs. M_{stop}

S. Heinemeyer, et al. arXiv:1112.3026

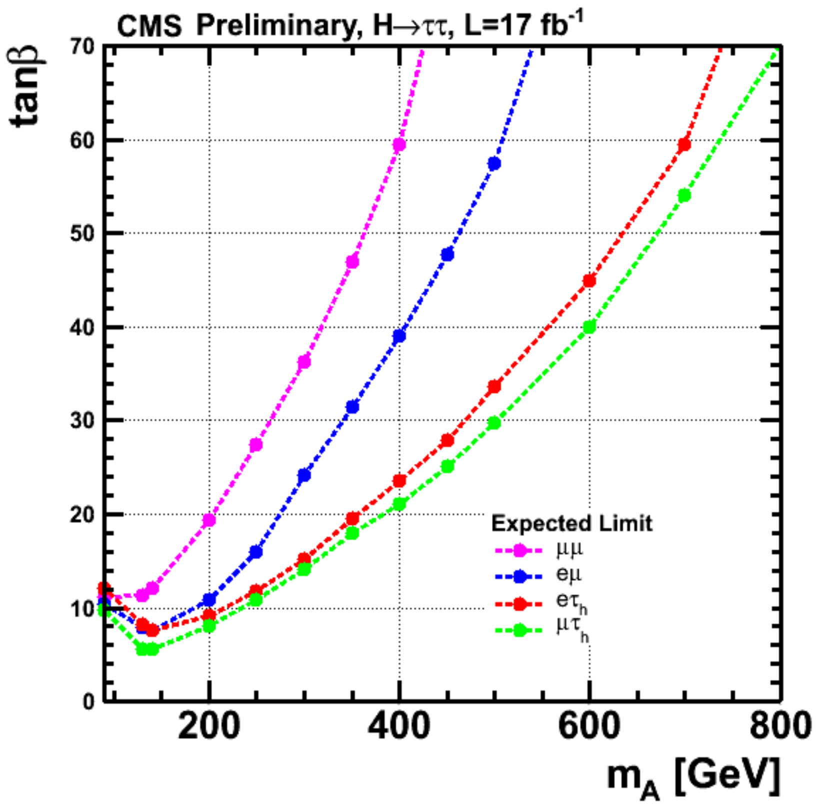
Y. Linke, G. W. '12

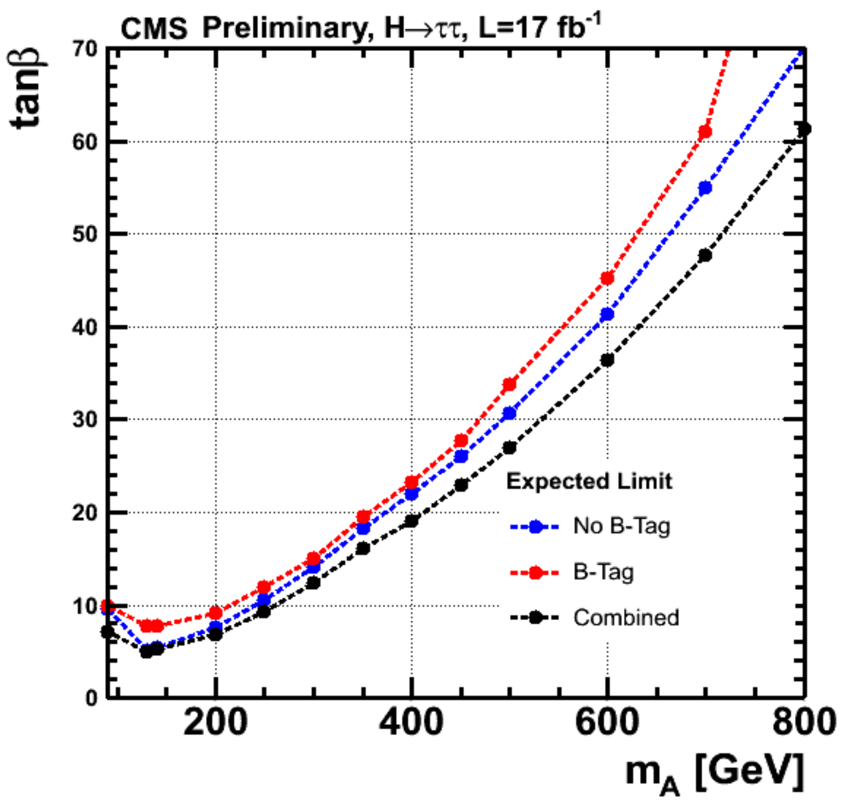


Modified $m_{h,max}$ scenario
$X_t \sim 1300$ GeV

Search sensitivity

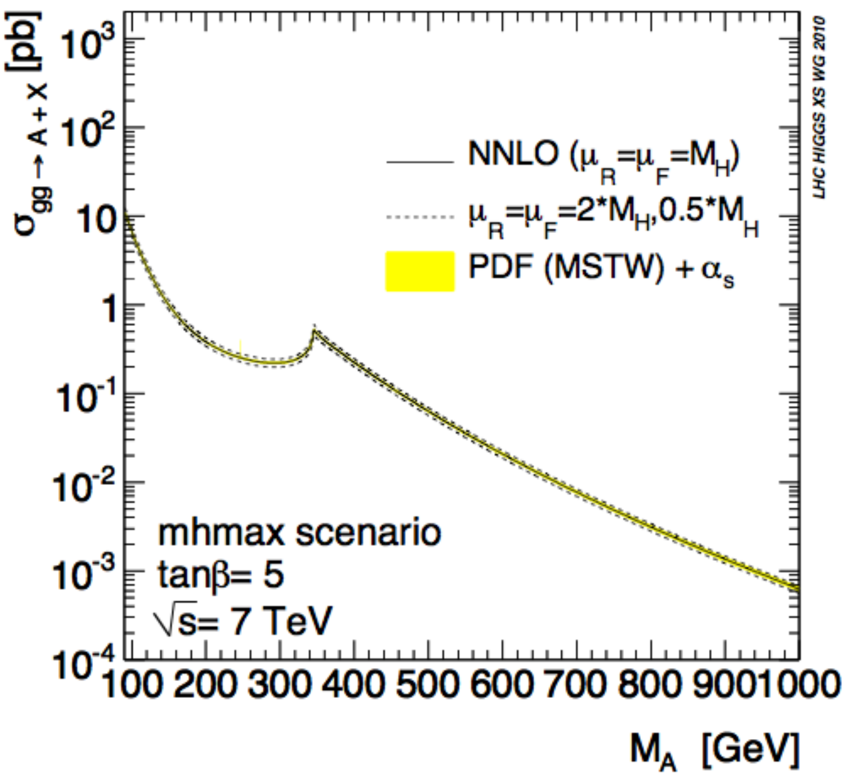
- Limits for different category/channel

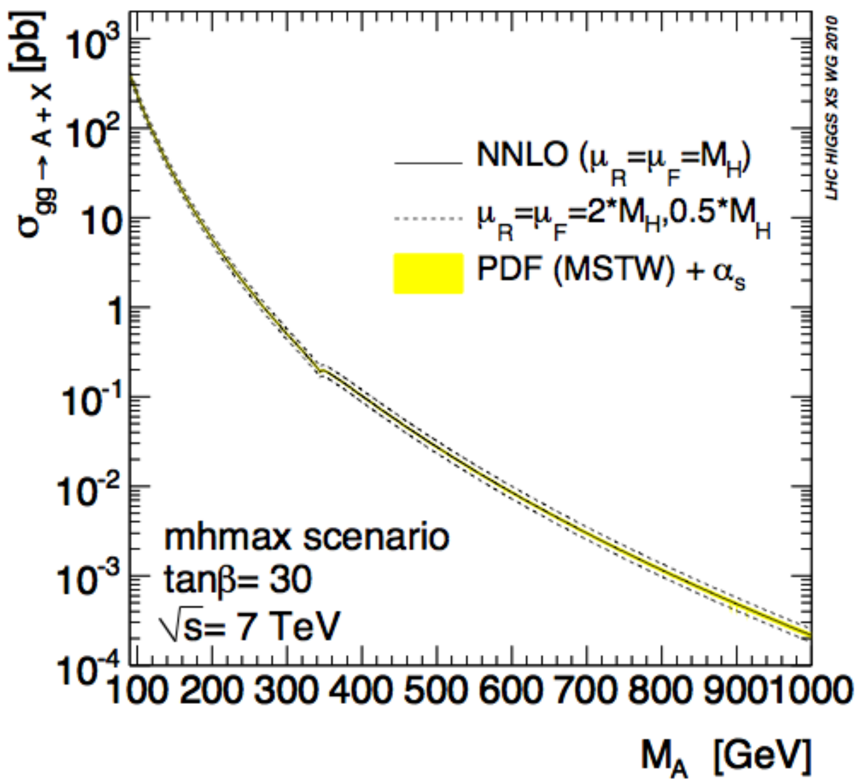




Cross section of gg fusion

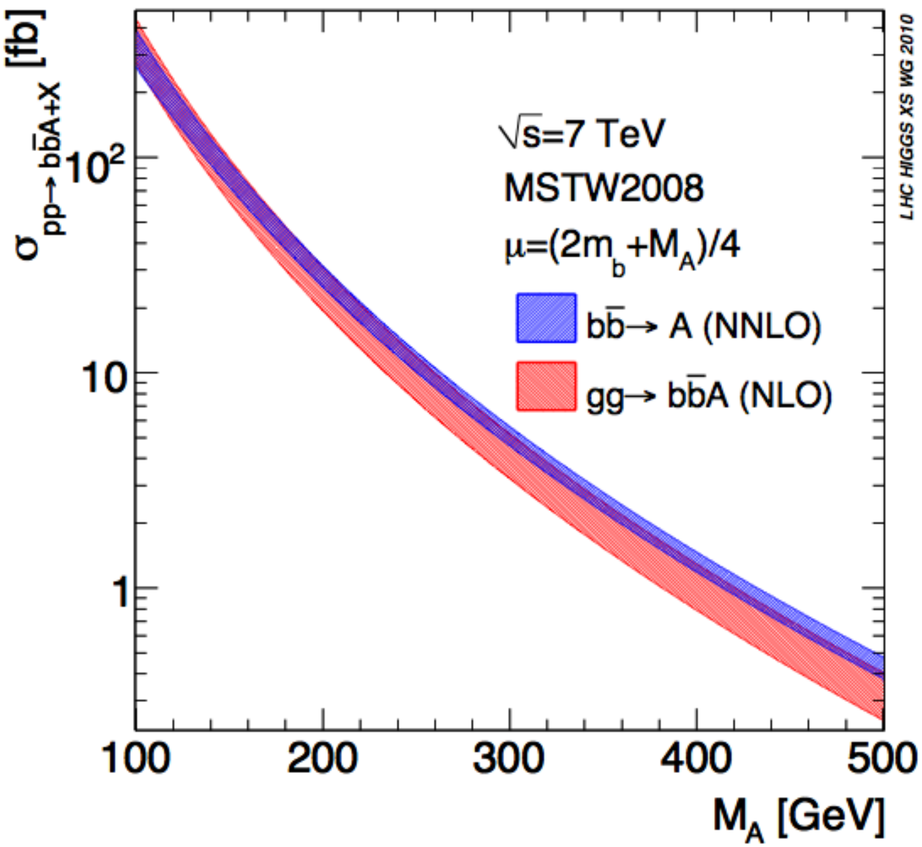
- Cross section of pseudo-scalar MSSM Higgs boson A in mh-max scenario



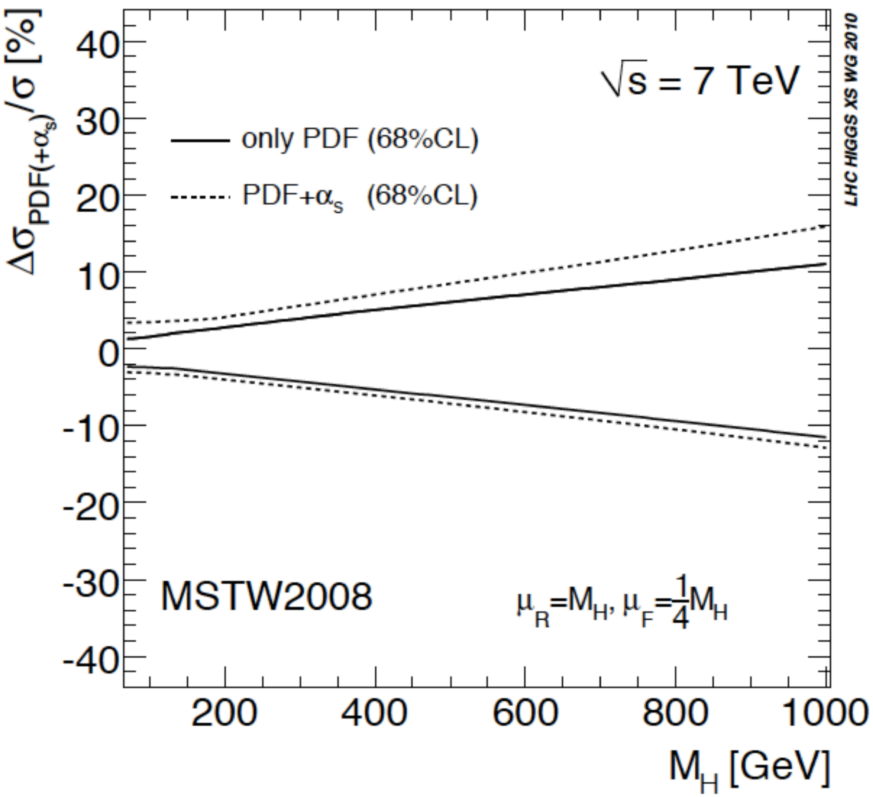


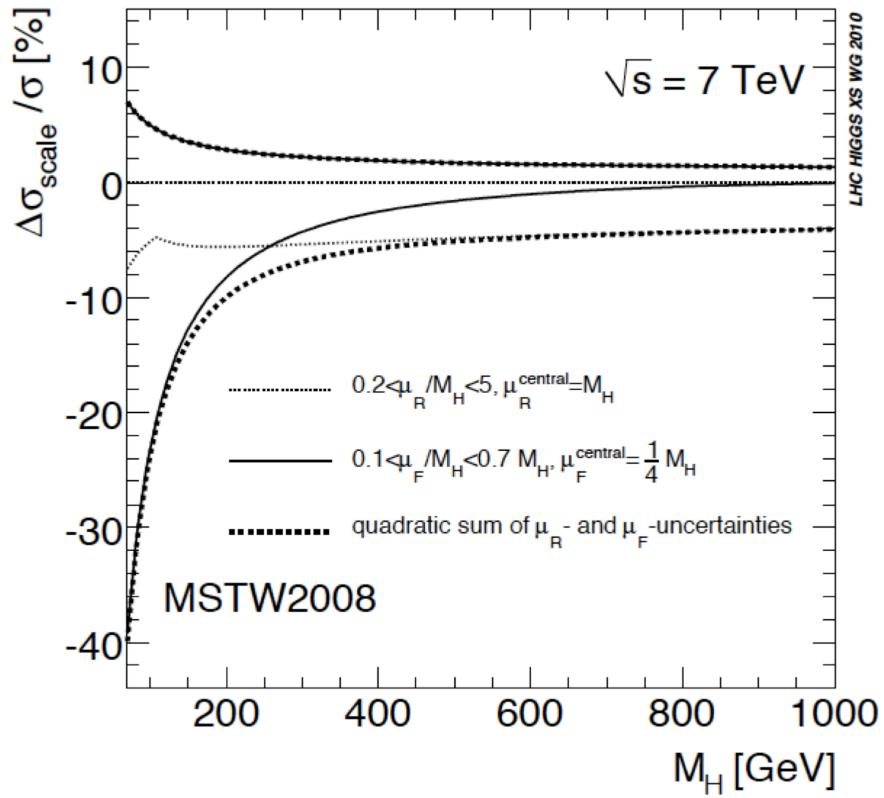
4FS vs 5FS

- Comparison of the NLO 4FS and NNLO 5FS for the production of pseud-scalar Higgs boson in association with b quarks in mh-max scenario



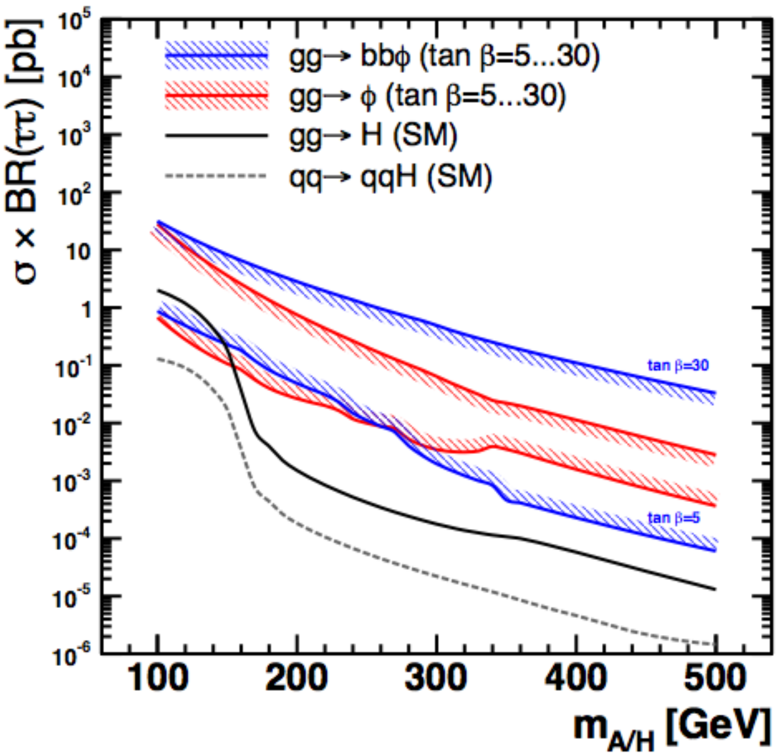
Theory uncertainty on σ(gg→bbΦ)

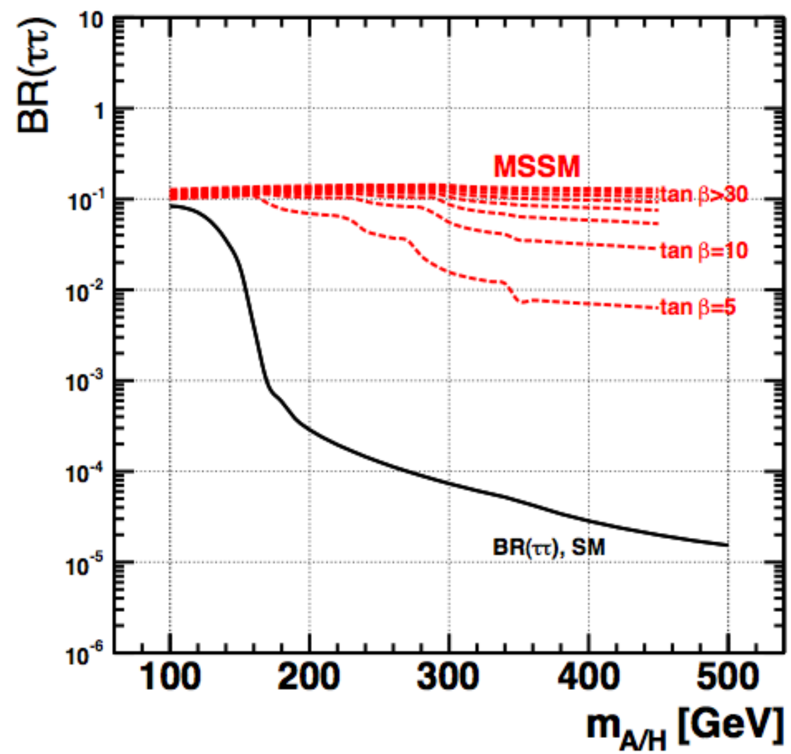




MSSM vs SM cross section

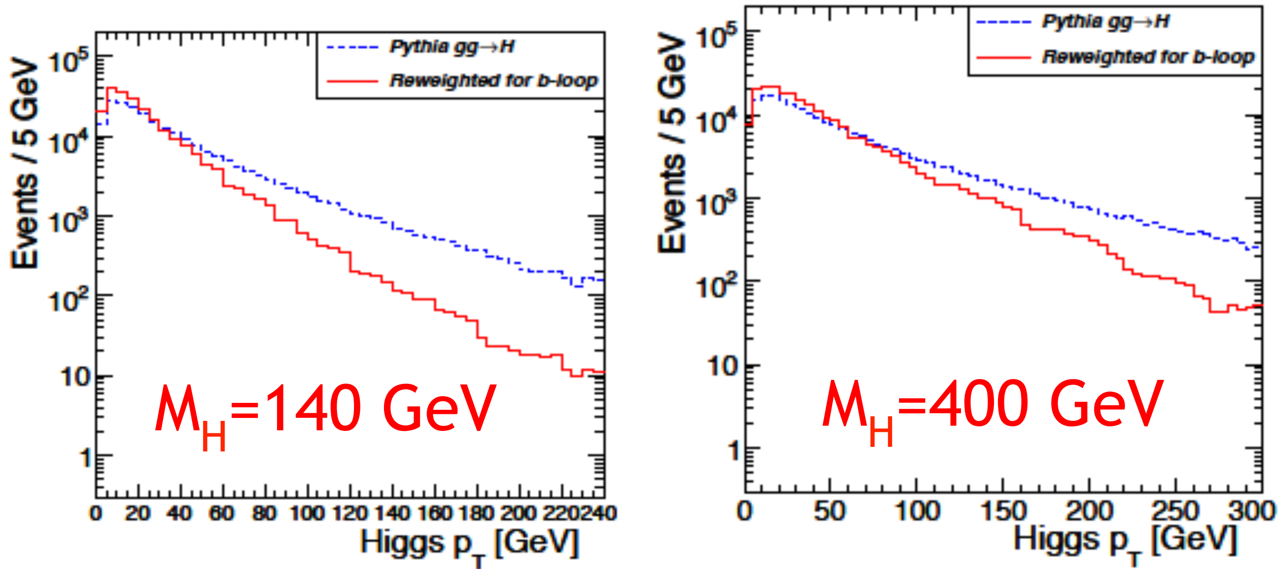
- Production cross section for the SM Higgs boson and the pseudo-scalar MSSM Higgs boson A





Effect of b-loop on acceptance of gg→Φ signal

arXiv:1201.3084 [hep-ph]



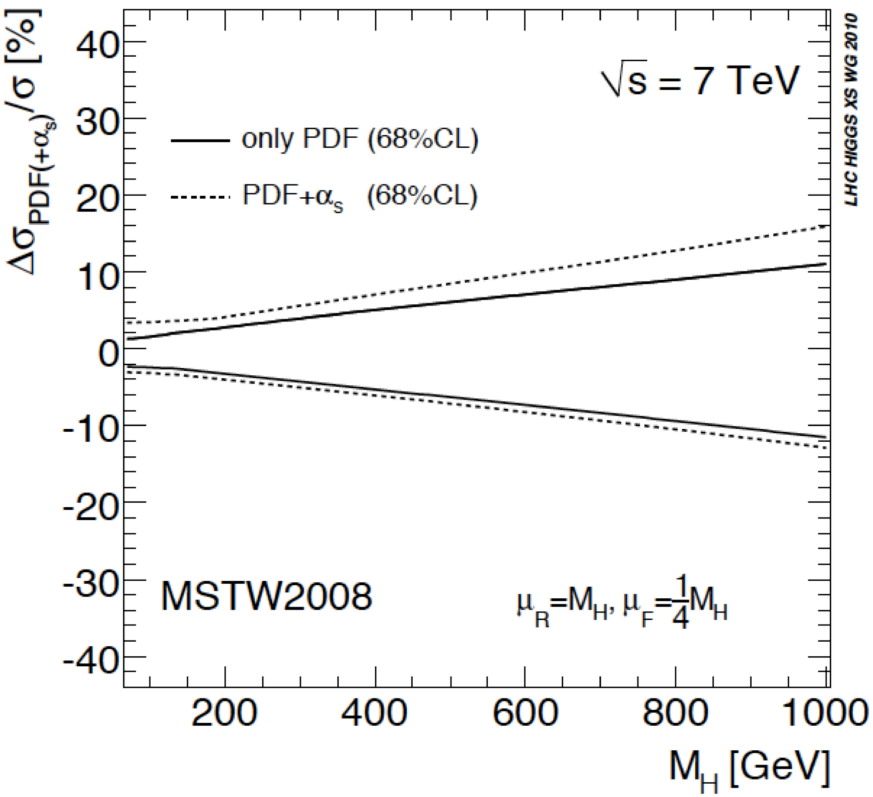
J. Alwall, Q. Li, and F. Maltoni, *Matched predictions for Higgs production via heavy-quark loops in the SM and beyond*, arXiv:1110.1728 [hep-ph].

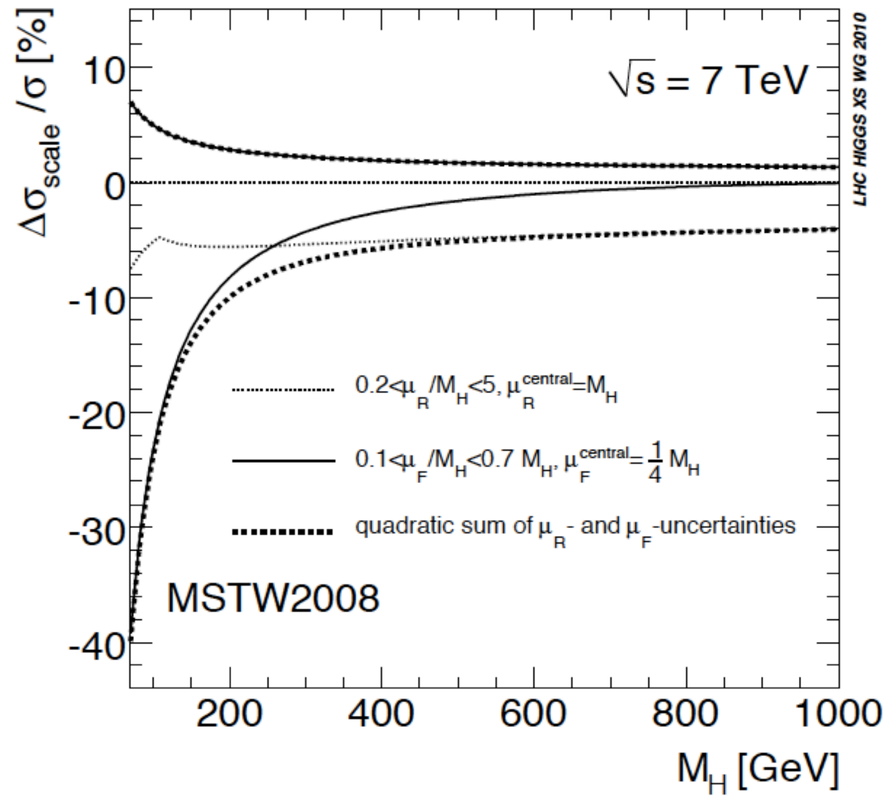
Table 41: The $e+\tau_h$ acceptances before and after re-weighting to correct for b-loop contribution.

M_H [GeV]	Acceptance PYTHIA $gg \to H$	Acceptance re-weighted for b-loop	Correction factor
140	0.072 ± 0.001	0.070 ± 0.001	0.97 ± 0.01
400	0.149 ± 0.001	0.152 ± 0.001	1.02 ± 0.02

For inclusive selection acceptance changes by 3%

Theory Uncertainties on $\sigma(pp \to bb\Phi)$





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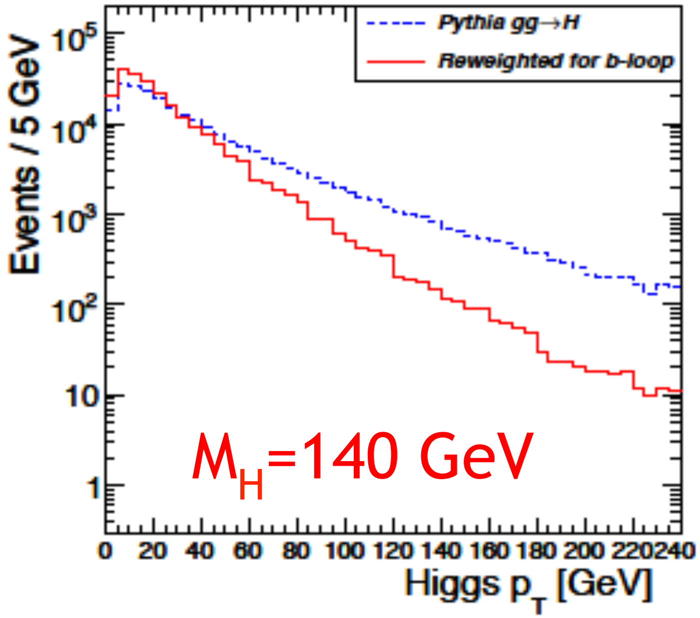

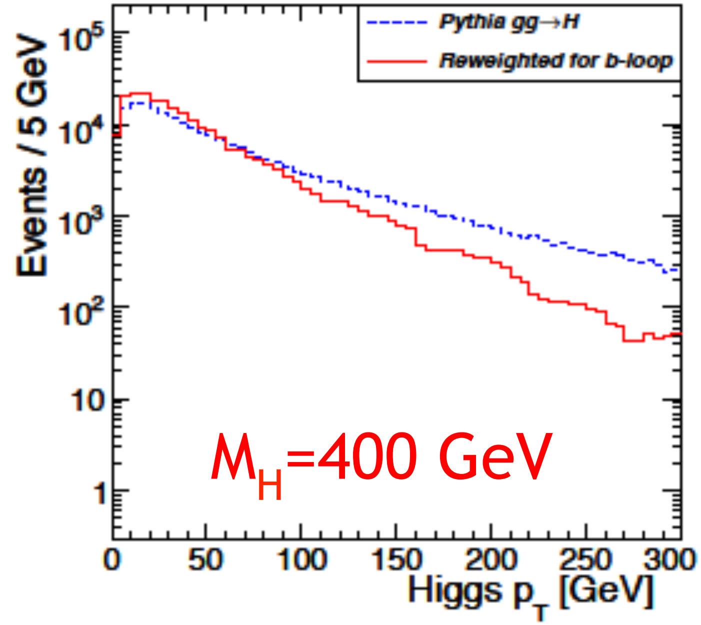

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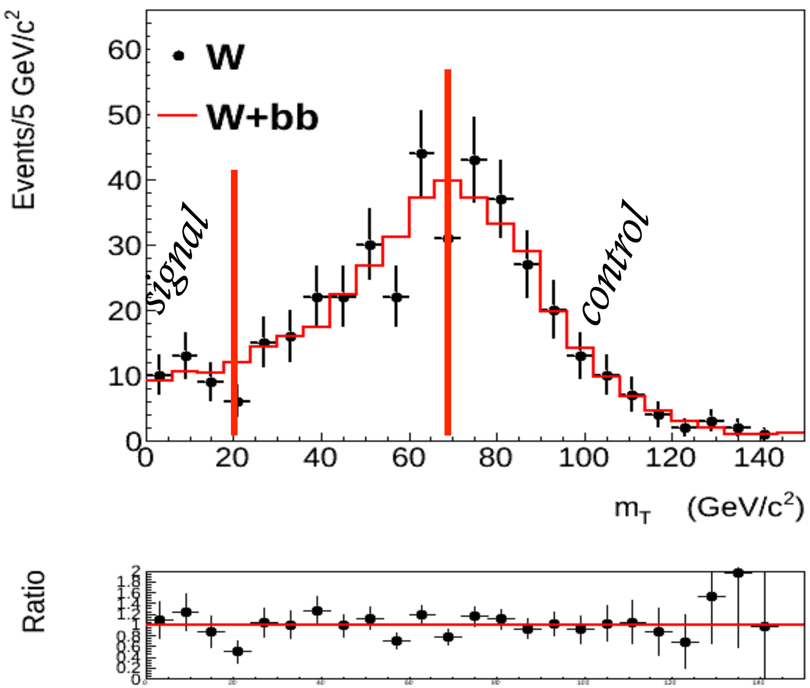
For inclusive selection acceptance changes by 3%

Backgrounds – Wjets

Transverse mass from Wjets and Wbb sample



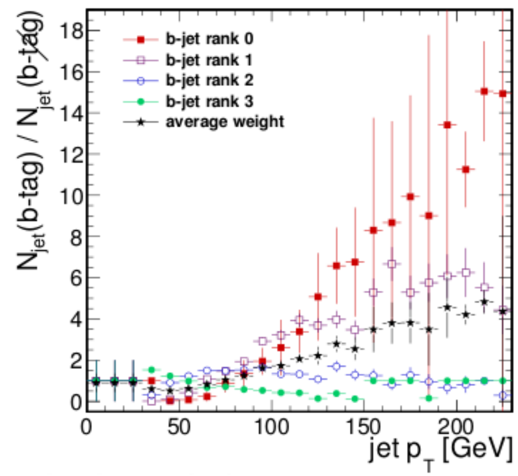
To mT<20 GeV

	Extrap. Factor stat unc.
W + light jet	0.13±0.01
W + b jet	0.15±0.03
W + jet	0.13±0.01

BACKUP for LQ/Stop

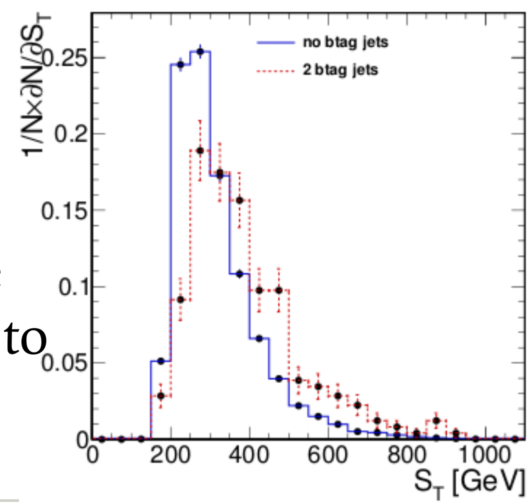
W/Z + jets S_T Shapes

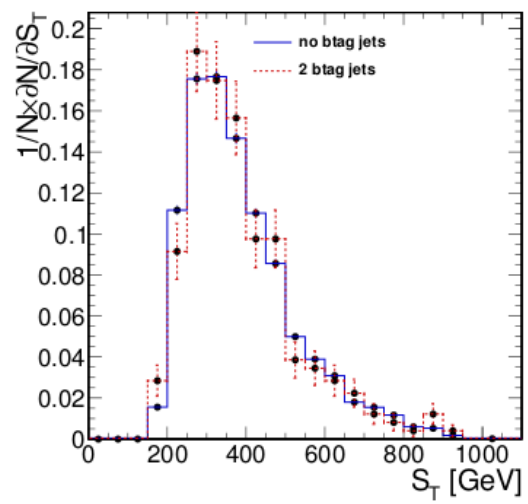
- Not enough statistics in MC after the main selection to get the W+jet and Z+jet S_T shapes with precision
  - Measure weight in independent sample
    - Z+1 jet events
  - S_T distr. is obtained by applying weights on control sample
    - At least two jets, no-btagging required



Validate procedure on anti-isolated control sample

- No overlap with main sample
- No overlap with sample used to compute weights





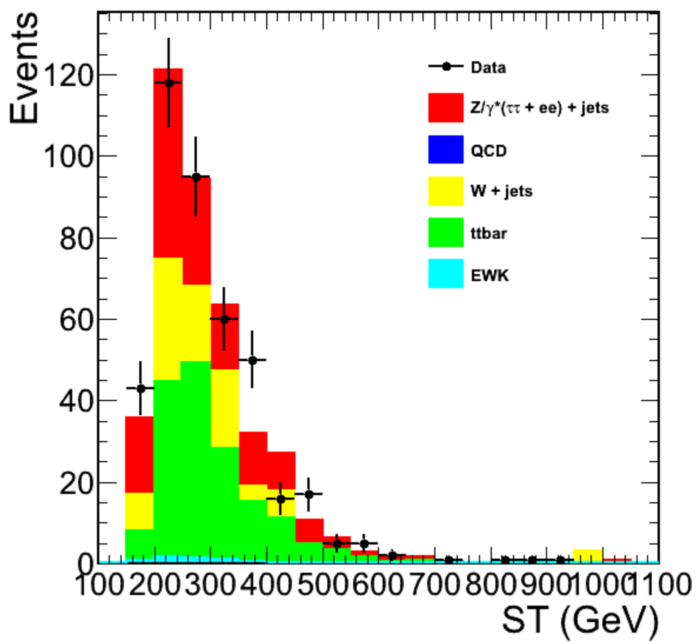
Systematic uncertainty on ST shape determination

- Parameterize S_T shape and compute $\pm 1\sigma$ variation of the fit taking into account errors on the fitting parameters
  - Novosibirsk function – Gaussian with exponential tail
    - Three parameters: mean, sigma, tail parameter

$$P(x) = e^{-0.5(\ln q_y)^2/\Lambda^2 + \Lambda^2}$$

with $$q_y = 1 + \Lambda(x - x_0)/\sigma \times \frac{\sinh(\Lambda\sqrt{\ln 4})}{\Lambda\sqrt{\ln 4}}$$

- Validate fitting function on control sample
  - Relaxing btagging requirement
  - Good agreement between data and MC

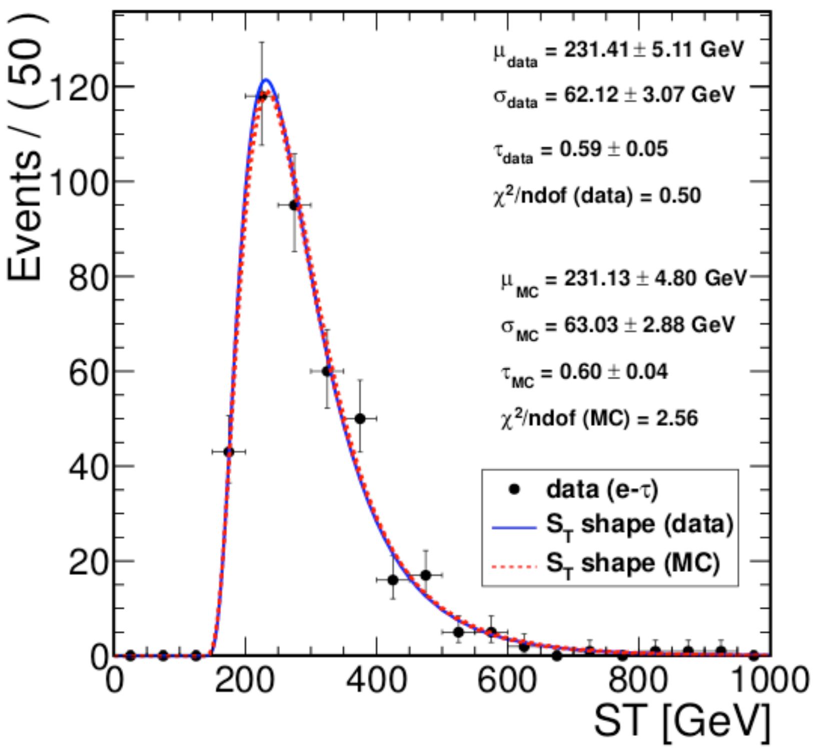


Data-MC fit comparison

- Very good agreement between data and MC fits
  - Red – data
  - Blue – MC

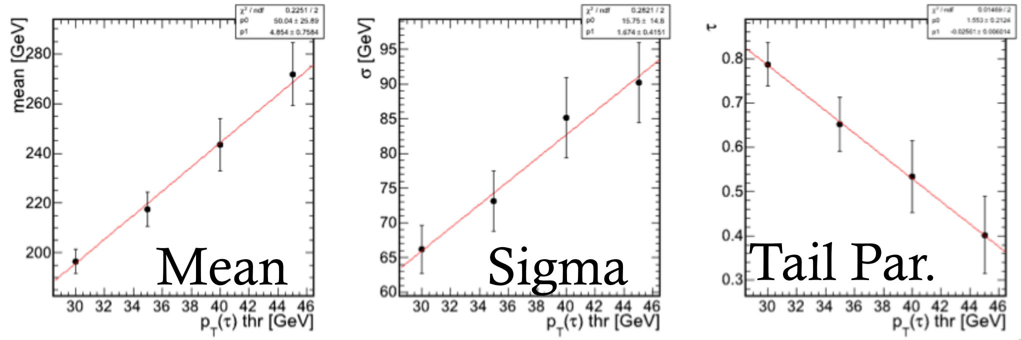
- For independent sample the function predicts the tail well

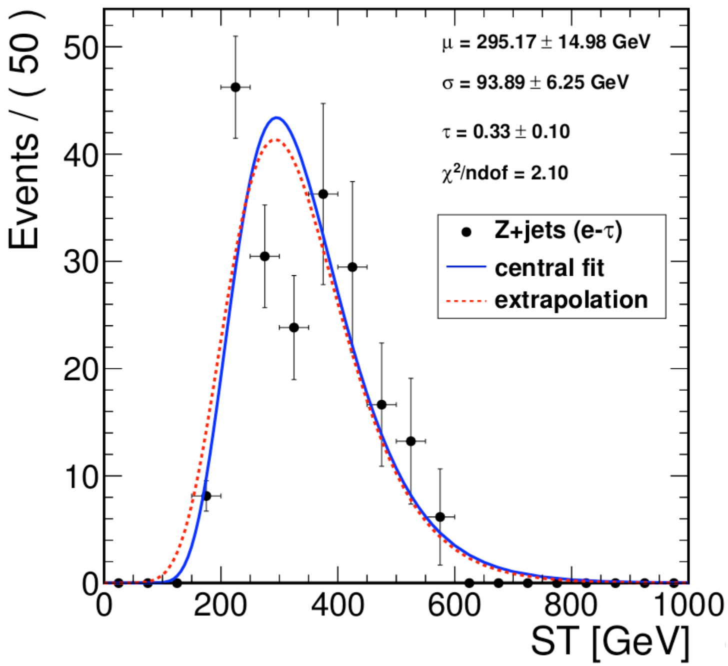
- Difference between data and MC at the tail is small



Fitting before M(tau,b) cut

- Obtain fitting parameters as a function of tau p_T
  - Extrapolated parameters for tau p_T>50 GeV





Tau p_T > 50 GeV

- Blue function -- the one fitted on the sample
- Red dashed function -- the one obtained by extrapolating the parameters

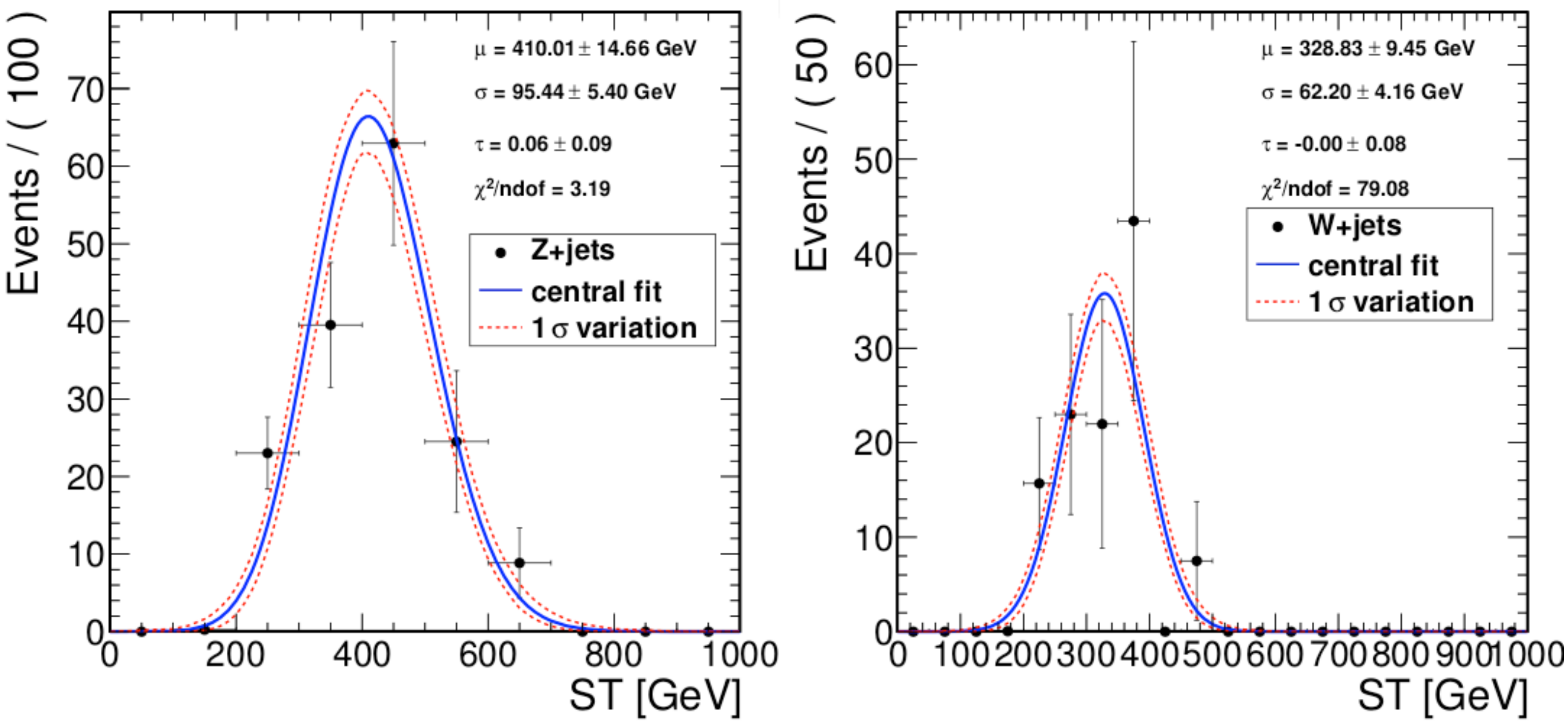
Conclusion:

* Difference between shapes (red and blue) is very small and can be neglected

* Parameters varied within uncertainties yields to shape systematic uncertainty on W/Z+jets

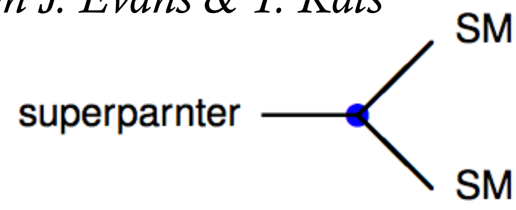
Fitting after final selection

- Nominal distribution and ±1σ variation of fit parameters for systematic uncertainties
  - Effect of these uncertainties is small



RPV interactions

From J. Evans & Y. Kats



$$W = \frac{1}{2}\lambda_{ijk}\, L_i L_j E^c_k + \lambda'_{ijk}\, L_i Q_j D^c_k + \frac{1}{2}\lambda''_{ijk}\, U^c_i D^c_j D^c_k$$

L = left-handed lepton/neutrino E = right-handed lepton

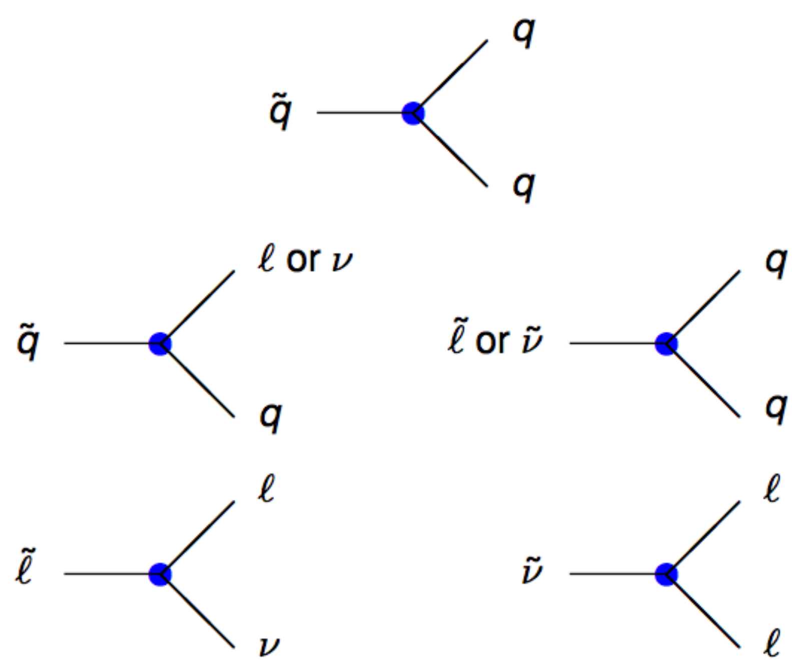
Q = left-handed quark U, D = right-handed quark

i, j, k = generation indices

UDD

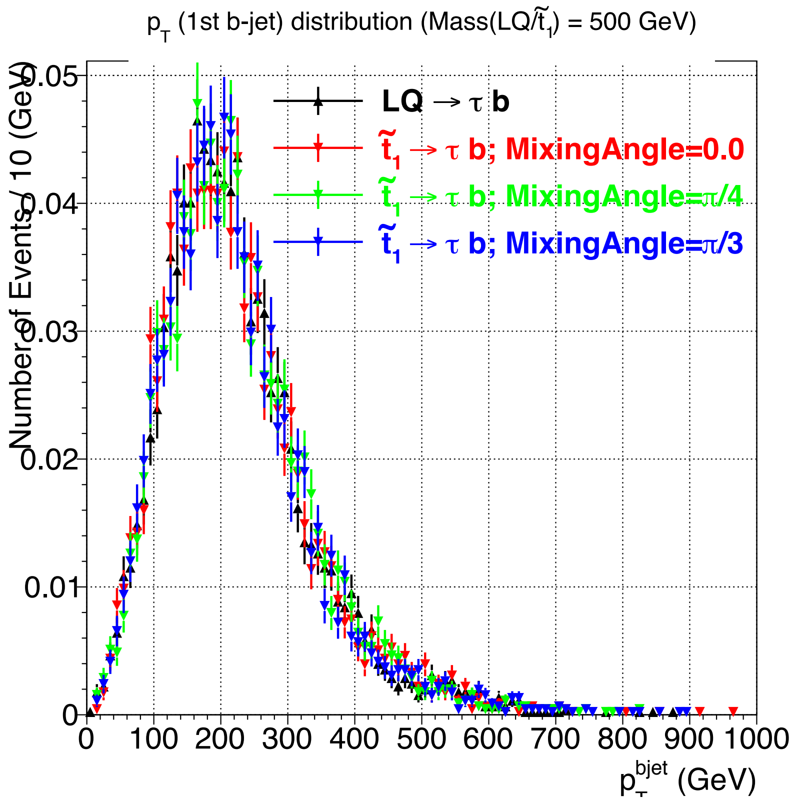
LQD

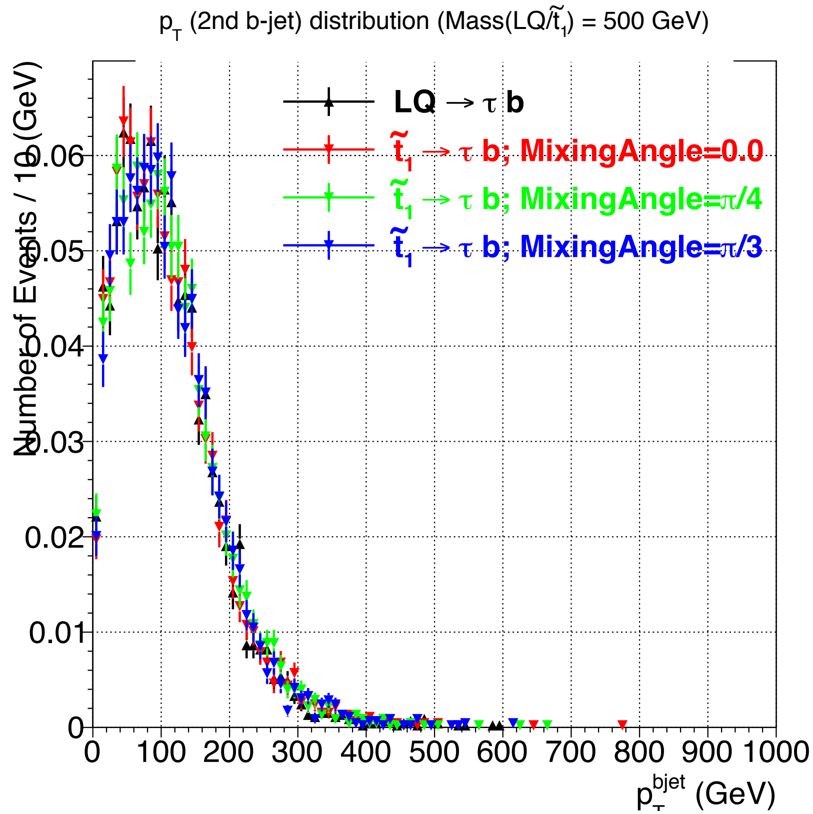
LLE



LQ vs stop kinematics I

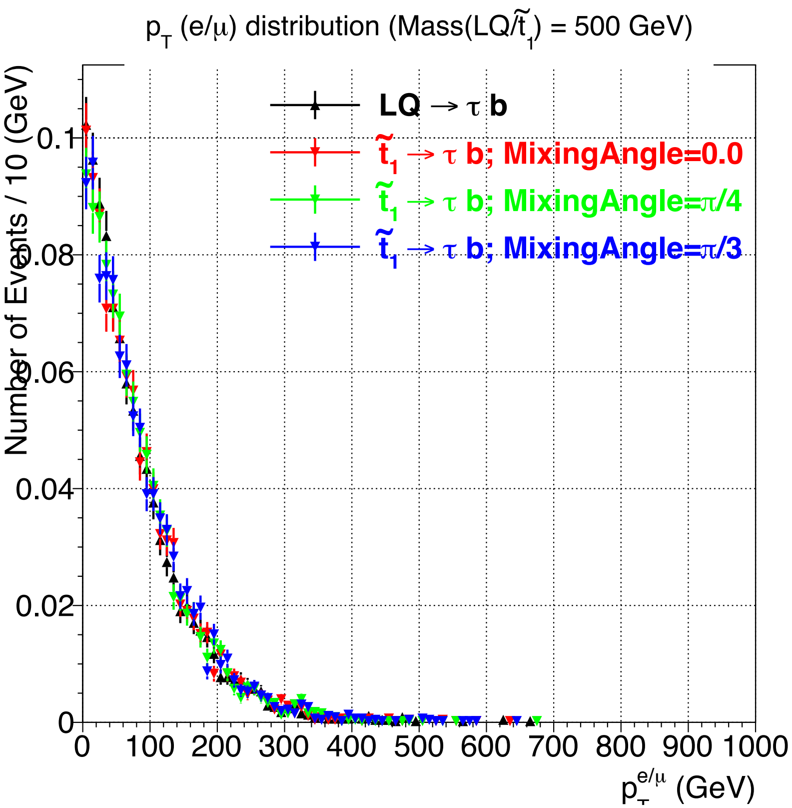
- First and second b quark p_T

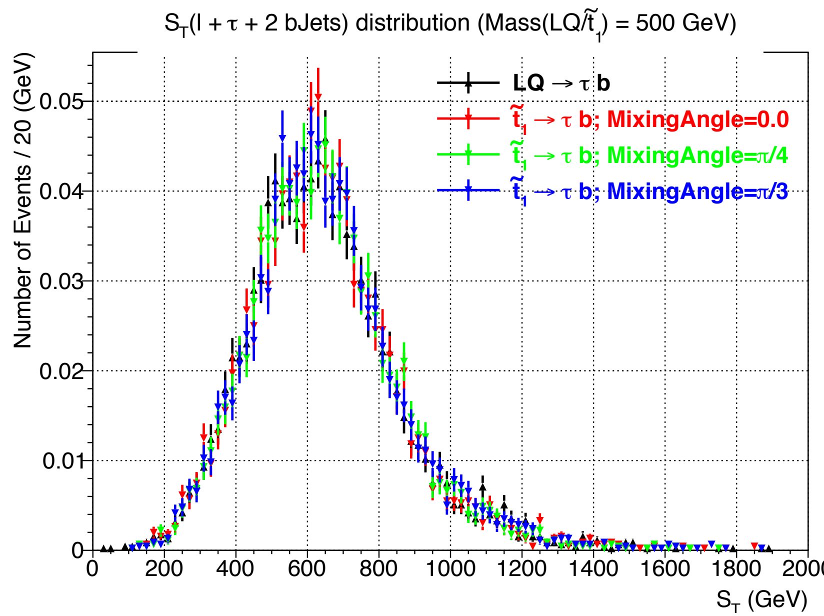




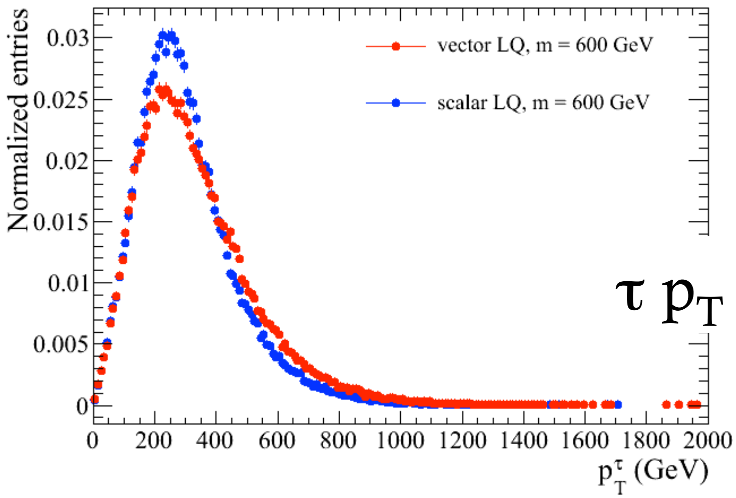
LQ vs stop kinematics II

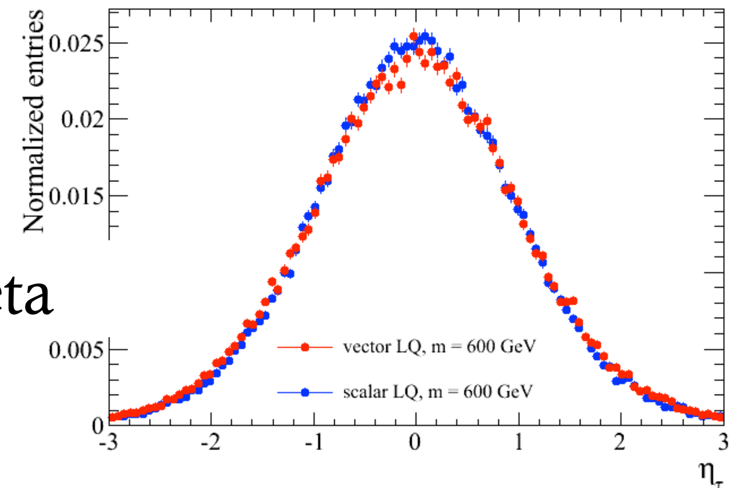
- Lepton pT and ST



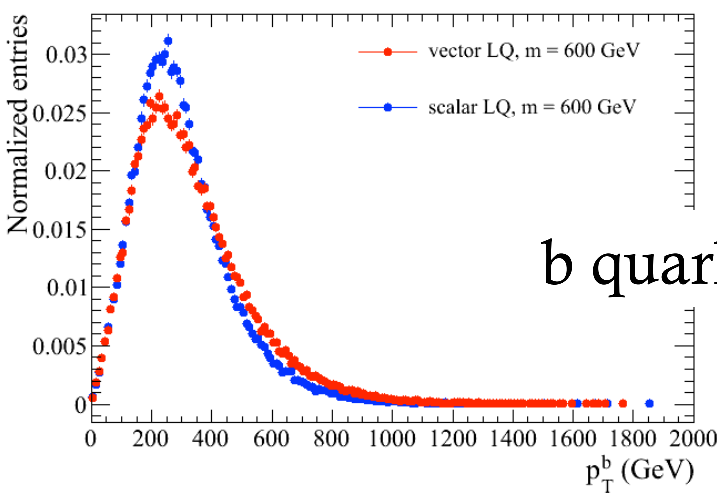


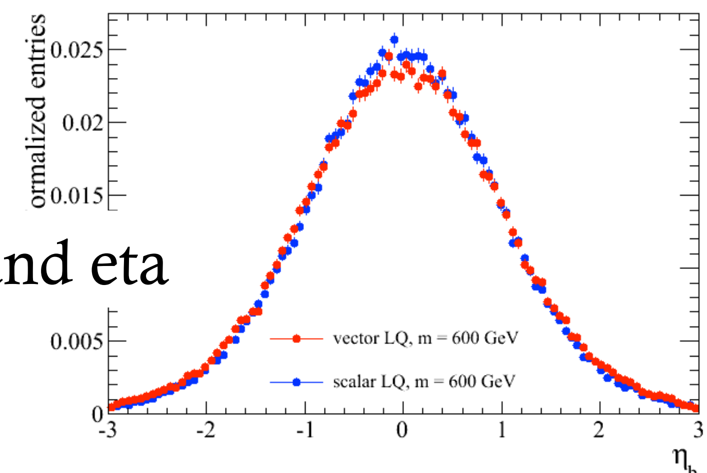
SLQ vs VLQ I





τ p_T and eta

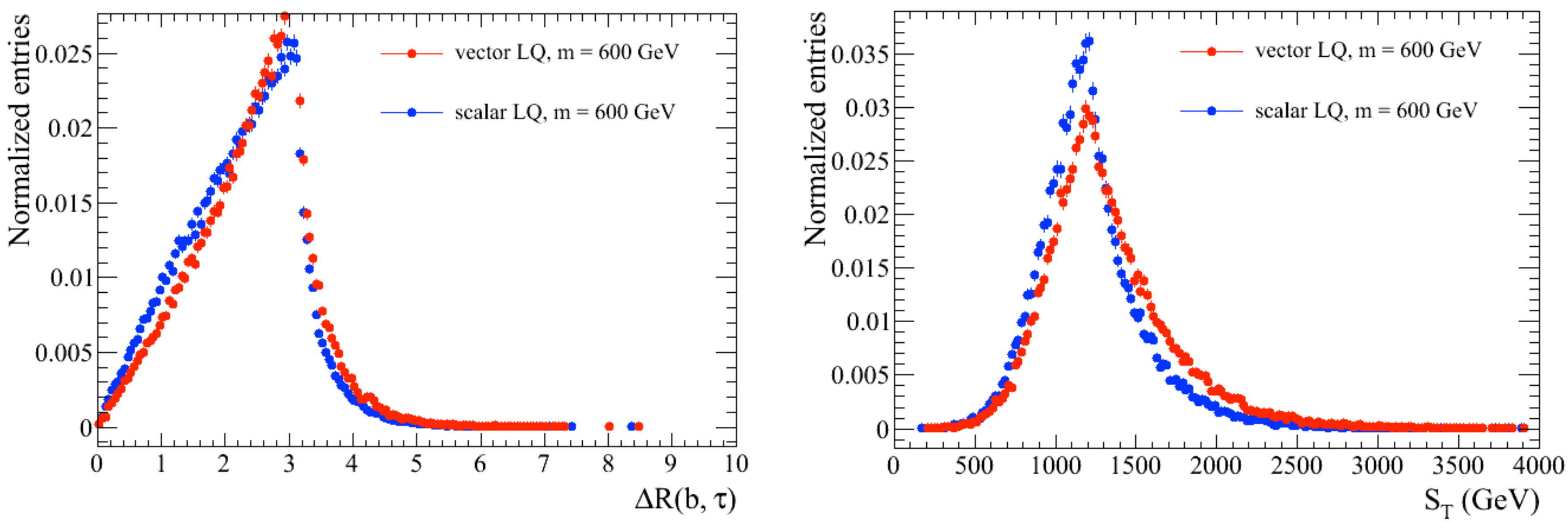




b quark p_T and eta

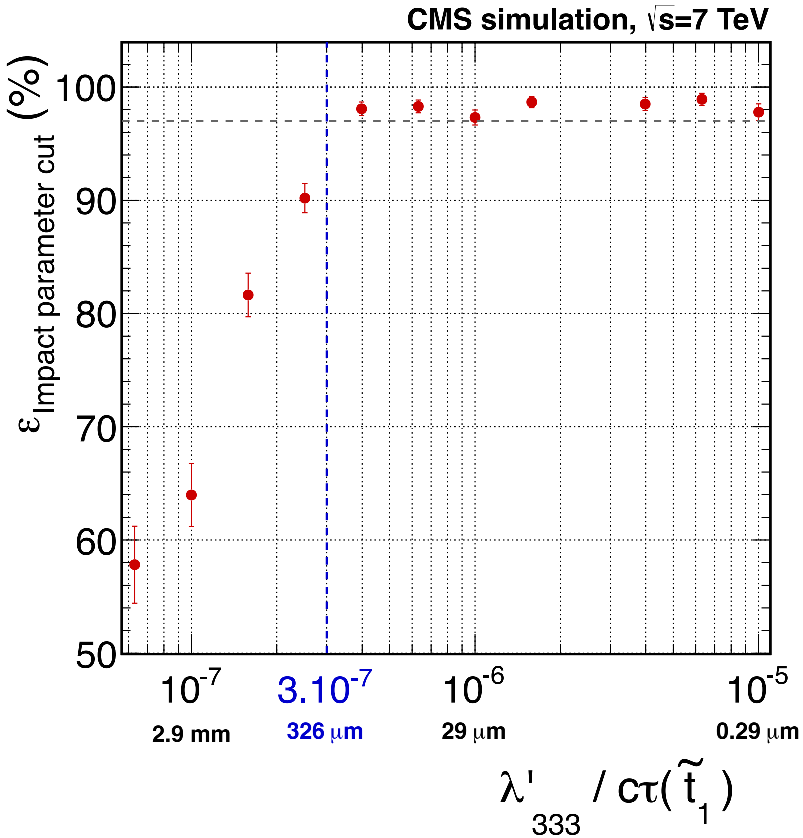
SLQ vs VLQ II

- ΔR and S_T



IP cut efficiency

- Impact parameter cut efficiency as a function of the RPV coupling λ'_{333} (RPV stop lifetime)



$$\tau = \frac{3.3.10^{-23}}{\lambda^2 \cos\theta^2 M_{\tilde{t}}}$$

limit on branching fraction

- Limit on β = BR(LQ3→τ b)